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DEVELOPMENT OF WILLOW CLONES FOR AGROFORESTRY AND BIOMASS ENERGY

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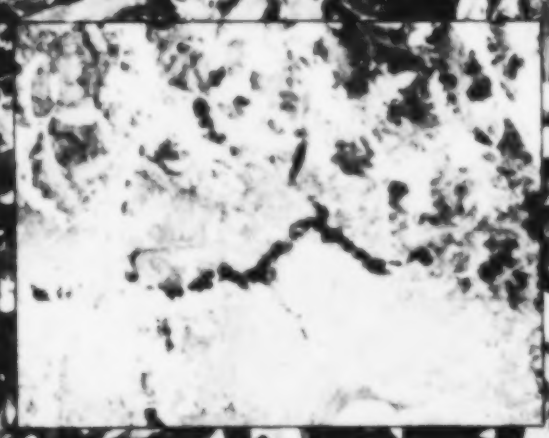
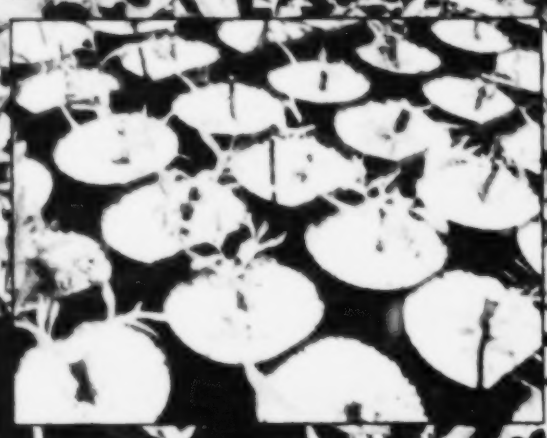
Development of Willow Clones for Agroforestry and Bioenergy





Final ADF Report

Submitted in January 2010 by:

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Development of Willow Clones for Agroforestry and Bioenergy

2010 ADF Final Report

SAF Agricultural Development Fund Project #20060145

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Cover Photos: Background: two-year-old SV1 hybrid willow growing at the Saskatoon plantation. Foreground: different ADF-funded research activities examining various environmental constraints influencing the viability of short-rotation willow plantations in Saskatchewan, such as: organic and inorganic nutrient amendments, drought and salt tolerance, and cold hardiness. (Photos taken by Sheala Konecsni and Ryan Hangs)

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1.0 Summary

Natural Resources Canada, along with a number of Canadian provinces, declares bioenergy to be a legitimate and sustainable source of energy that will constitute a significant portion of future energy production needs. The establishment of short-rotation intensive culture (SRIC) plantations, such as fast-growing shrub willow (*Salix* spp.), represents a compelling purpose-grown bioenergy crop option. The broad objectives of this research were to: 1) Establish willow clonal trials at several locations throughout Saskatchewan; 2) Determine which hybrid willow clones demonstrate the best survival and growth characteristics for use in Saskatchewan; 3) Determine biomass yields and develop allometric equations for different willow clones; 4) Determine the best cultural practices for willow establishment, survival and growth as well as costs for establishment; and finally, 5) Determine whether the measured differences in field performance among hybrid willow clones are attributable to one or more physiological clonal differences. Four willow clonal trials were established throughout Saskatchewan (Estevan, Saskatoon, Birch Hills, and Prince Albert) and over a three-year period, productivity assessments were completed, plant tissues sampled and analyzed for determining nutrient and water use efficiency, along with the development of allometric models for estimating above-ground biomass non-destructively. Soil samples were also collected at each site and along with the detailing of costs associated with all aspects of establishing and maintaining willow plantations. The initial establishment costs are currently ~$6700/ha, which is a considerable investment due to the high cost of planting material (~65% of total costs). However, with future market competition, cutting material costs could be reduced by 60% making willow establishment more feasible especially if planting is once every 22 years. The clones studied demonstrated acceptable survival characteristics but the heavy clay soils in Saskatoon resulted in lower yields compared to the other sites in the province likely due to water limitations on these soils. Additionally, three additional studies (two field studies and one growth chamber study) were established in Prince Albert and Saskatoon to examine the effects of fertilization and irrigation on willow biomass production. Irrigation had a significant impact on willow growth on heavy clay and supported economically viable biomass production levels. Although there was no effect of applied fertilizer, balanced fertilization is required to support the long-term soil productivity necessary for a sustainable biomass energy production system. Another growth chamber study compared the relative salt tolerance of 37 different native and exotic hybrid willow clones grown on soils with varying salinity. Most willow clones tested were able to tolerate slightly saline conditions ($\leq$ 5.0 dS/m), while several clones (Alpha, India, Owasco, Tully Champion, and 01X-268-015) showed no reduction in growth with moderately salinity ($\leq$ 8.0 dS/m). A tremendous opportunity exists to develop non-consumable woody crops as a bioenergy feedstock, especially if they can be successfully grown on millions of hectares of marginal land or land that is saline and deemed unsuitable for annual crop production. Overall, this research work has provided the first research on the agronomy of growing willow and helped to fill the knowledge gap regarding cultivating SRIC willow plantations in Saskatchewan and, therefore, should help support effective management decisions regarding the successful establishment and growth of willow plantations.

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2.0 Introduction

As the world population continues to increase exponentially, the need for a reliable and sustainable source of energy is becoming progressively more important. In addition, given the volatility of oil supply and environmental issues concomitant with petroleum-based energy, it is readily apparent that an alternative renewable clean energy source is needed to meet future demands. Currently, the use of biomass-derived energy accounts for approximately 10% of the global energy requirement (Berndes et al. 2003); however, with a growing desire worldwide for a secure and environmentally-friendly energy source, there is increased interest in developing biomass production systems for use as a dedicated or 'purpose-grown' feedstock for bioenergy production. Canada is no exception, with its high per capita energy consumption and the majority of its energy demand used for transportation and building utilities (Cuddihy et al., 2005). The current Saskatchewan government in the 2009 Throne Speech stated that biomass needs to be investigated as a potential energy option in order to meet Saskatchewan's future energy needs in an affordable, reliable and environmentally friendly manner. Willow as a woody biomass crop could provide Saskatchewan with that option for renewable energy as well as providing other environmental benefits, especially in the area of carbon sequestration. The establishment of SRIC plantations, such as fast-growing shrub willows (*Salix* spp.), therefore, represents a legitimate option for diversifying farmers trying to maintain an economically viable operation in the face of historically decreasing commodity prices, along with increasing input and transportation costs, especially in the northern regions where annual crops are grown on marginal agricultural soils.

Before there is widespread adoption of willow plantations (assuming markets are available), there needs to be a clear understanding of willow agronomy for producers. In order to achieve this goal, conclusive documentation of adequate survival and growth of planted willows is required, which was established through this three-year research project; consequently, a number of important agronomic questions need to be addressed, which were the focus of this research project over the last three years. The overall objective of this research was to determine the viability of growing multiple rotations of SRIC willow as a bioenergy feedstock within Saskatchewan. The specific research objectives of this study were to:

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1. Establish willow clonal trials at several locations throughout Saskatchewan and determine which clones have the best survival and growth characteristics in Saskatchewan.
2. Determine biomass yields and develop allometric equations for different willow clones.
3. Determine the best cultural practices for willow establishment, survival and growth, as well as costs for establishment.
4. Determine the most efficient and effective methods of estimating above-ground biomass within these plantations.
5. Examine whether the measured difference in field performance among hybrid willow clones is attributable to one or more physiological (i.e., water use efficiency, nutrient use efficiency, or cold hardiness) clonal differences.
6. Assess the effect of different rates of both inorganic and organic fertilizer N on the biomass production and fertilizer use efficiency (using the stable isotope ^{15}N as a tracer) of different willow clones.
7. Determine the effects of irrigation and fertilization on willow productivity.
8. Determine the salt tolerance of different native and exotic willow clones.

3.0 Methods

3.1 Hybrid Willow Clonal Trial

3.1.1 Study Sites

The data for this study is being collected from four hybrid willow plantations located throughout Saskatchewan (Figure 1): i) the first site is located at the Pacific Regeneration Technologies Inc. nursery approximately 18 km north of Prince Albert on Highway #2 North (105°46'26"W, 53°21'18"N); ii) the second site is located on farmland approximately 6 km northwest of Birch Hills (105°29'24"W, 53°00'08"N), iii) the third site is located at the University of Saskatchewan Horticulture Field Lab, adjacent to the 14th street overpass (106°36'28"W, 52°07'37"N), and iv) the fourth site is located approximately 10 km southeast of Estevan, directly behind SaskPower's Shand Power Station (102°52'35"W, 49°04'36"N). Although this fourth site was not initially included in the original proposal, given SaskPower's interest in the potential use of biomass for energy, when

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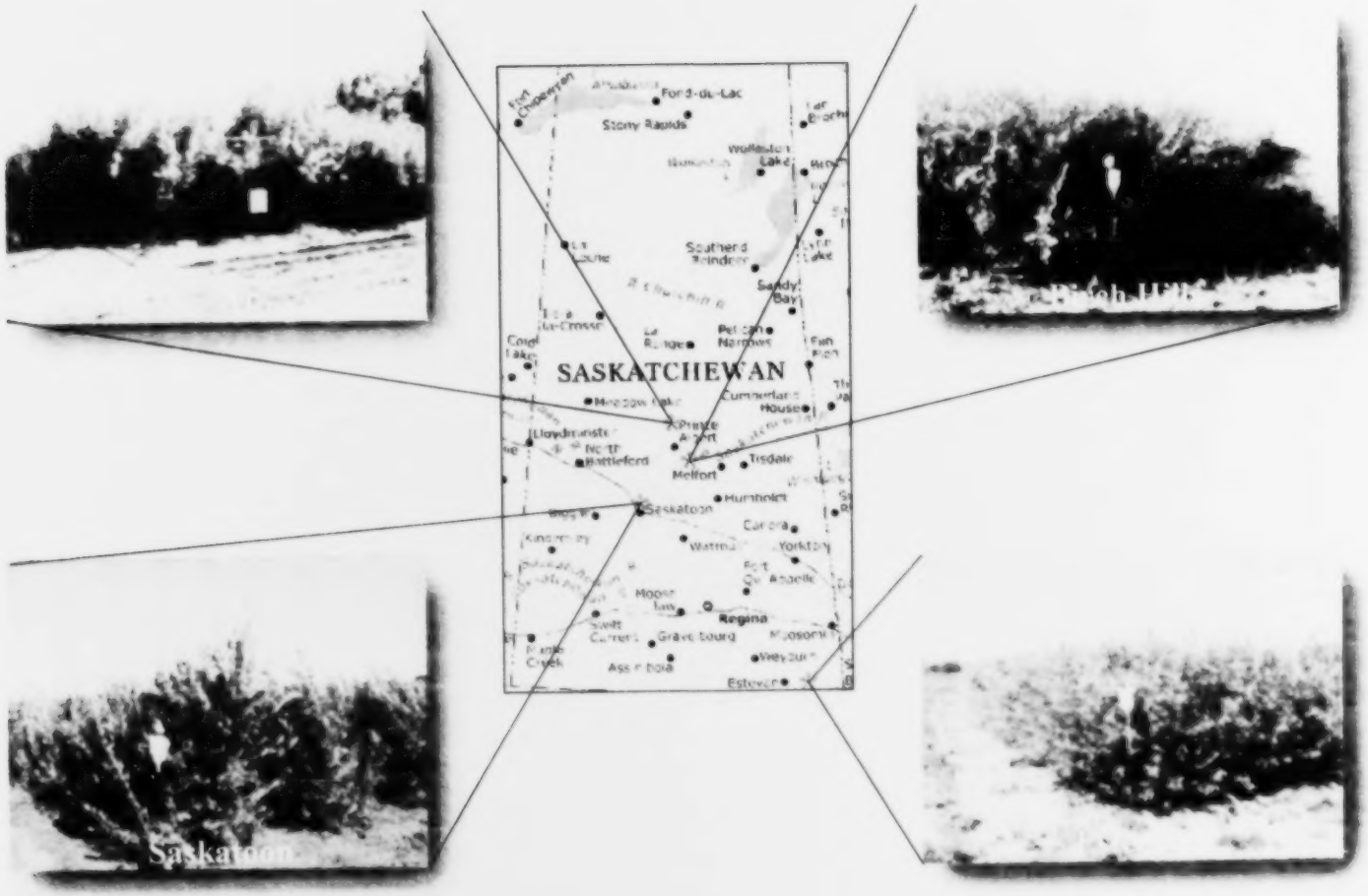

Figure 1. Second year post-coppice growth of hybrid willow established at various Saskatchewan locations in 2007.

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approached by them to include a study site adjacent to their power station, its inclusion was deemed prudent. These four sites are an excellent representation of the diverse soil type and climatic conditions present within Saskatchewan (Table 1). This site diversity is advantageous in that it allows for a greater inference space of the study results, in terms of providing useful recommendations, based on the measured growth responses of planted willow at each site. As described in the next section, all sites underwent mechanical (i.e., tillage and hand weeding) and chemical (i.e., pre- and post-emergent) site preparation prior to planting and throughout each growing season (Table 1).

3.1.2 Site Establishment and Maintenance

The one-year-old hybrid willow clones used in this study was provided by Dr. Tim Volk from the State University of New York College of Environmental Science and Forestry (SUNY-ESF), which has been studying the cultivation and use of willow biomass as a bioenergy feedstock for more than 10 years. These hybrid willow clones, which are some of the best performers within SUNY-ESF's extensive breeding program, were harvested from production stooling beds, sectioned into 25 cm long cuttings (diameters ranging from 8 to 21 mm), bagged, stored at -4 ^{o}C, and subsequently couriered to Saskatoon. It is expected that this entire procedure has no adverse effect on outplanted willow cutting vigour or survival (Volk et al., 2004a). Planting of the stem cuttings at the four sites was completed between late May and early June 2007. Prior to planting, the cuttings were submerged in water for at least 12 hours. The aim was to plant each unrooted dormant cutting flush with the ground (Kopp et al., 2001; Tharakan et al., 2005); however, given that numerous individuals were utilized to plant the cuttings at each site in a timely manner, a consistent planting depth could not be guaranteed. Instead, the planting depth of cuttings ranged from 3 cm below-ground to 4 cm above ground. In the spring of 2008, prior to bud break, all of the willow plants within each plot were cut down to approximately 2-4 cm above ground level (Figure 2), to encourage coppicing (i.e., the production of a large number of shoots when a single stem is removed, but the established willow root system remains intact). Consequently, the first-year willow coppice will begin growing on one-year-old root systems. Willow harvesting occurs three years after coppicing for 7 rotations and this willow biomass production system is based on SUNY-ESF's extensive research work into the commercial development of willow crops.

One of the most important aspects of establishing a successful willow plantation is to perform adequate site preparation prior to planting. This is a critical step, as insufficiencies at this stage invariably will result in elevated weed control requirements throughout the entire rotation. Every year,

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Table 1. Selected characteristics of four hybrid willow clonal trial field sites located throughout Saskatchewan.

Site	Soil Characteristics			Site Characteristics					Weed Control Practices			
									Pre-planting		Post-planting	
	Association	Soil Type	Texture	Prior Crop	ACC*	MAP†	MAT‡	FFD§	Mechanical	Chemical	Mechanical	Chemical
Saskatoon**	Sutherland	Orthic Vertisol	sandy-loam to loam	barley/oats	2-3	375	2	112	Deep till	Goal 2XL (2 L ha^{-1})	Between-row tillage and hand weeding	Glyphosate (2 L ha^{-1}) Bromoxynil (0.5 L ha^{-1}) Goal 2XL (2 L ha^{-1})
Prince Albert††	Pine	Orthic Eutric Brunisolic	sand to loamy-sand	summerfallow	5-6	450	0	85	Deep till	Goal 2XL (2 L ha^{-1})	Between-row tillage and hand weeding	Goal 2XL (2 L ha^{-1})
Birch Hills‡‡	Hocy-Blaine Lake	Orthic Black Chernozem	silt-loam to clay-loam	canola	1-2	420	1	90	Deep till	Goal 2XL (2 L ha^{-1})	Between-row tillage and hand weeding	Glyphosate (2 L ha^{-1}) Goal 2XL (2 L ha^{-1})
Estevan§§	Alluvium	Orthic Regosol	clay-loam	summerfallow	3-4	430	4	124	Deep till	Goal 2XL (2 L ha^{-1})	Between-row tillage and hand weeding	Glyphosate (2 L ha^{-1}) Goal 2XL (2 L ha^{-1})

* Agriculture capability classification (Class 1: no significant limitations; Class 2: moderate limitations; Class 3: moderately severe limitations; Class 4: severe limitations; Class 5: very severe limitations; Class 6: limited capability for arable agriculture).
† Mean Annual Precipitation (mm).
‡ Mean Annual Temperature (^{0}C).
§ Frost-free days.
** For a complete description (i.e., map unit, parent material, stoniness, drainage, etc.) see SCSR (1978).
†† For a complete description see SCSR (1976).
‡‡ For a complete description see SCSR (1989).
§§ For a complete description see SCSR (1997).

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Figure 2. Cutting back one-year-old hybrid willow clones to promote coppicing in spring

each site received mechanical and chemical vegetation management practices (Figure 3 and Table 2). The level of maintenance required to control non-crop species was site dependant; however, it is expected that by the third growing season, weed control measures will be unnecessary, due to willow canopy closure shading out any understory non-crop species. It cannot be overstated that regardless of soil type, drainage, or previous crops, starting out with a clean weed free plot area is critical to subsequent plantation success.

Initially, the land should be mechanically worked (i.e., deep tillage) to break up larger soil aggregates and adequately aerate the soil. Following this, a tank mix of Treflan and Sencor could be applied as a pre-emergent to the plot area. In the first growing season, the pre-emergent application of Treflan/Sencor should control the majority of weeds on the field. If weeds begin to grow, glyphosate can be applied with a hooded spray applicator in between the rows to control the weed situation. In the fall, after the first growing season, apply a spray application of Linuron as a pre-emergent for weed control for the following growing season. For our research plots, Goal 2XL was used as a pre-emergent and this herbicide is currently going through the registration process for willow plantations. For annual grass and thistle control during the growing season, Poast Ultra and Lontrel can be tank mixed at the recommended rate and applied while the willow is actively growing. If possible, direct the spray pattern down so that minimal chemical comes into contact with the willow plant. For general weed control in between rows, glyphosate can be applied using a hooded spray applicator towed with a small tractor or ATV. Glyphosate is inexpensive and works well on most weeds in general but caution

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Figure 3. Various vegetation management methods to control non-crop species in this study

Table 2. Rates and associated cost of chemicals used to control non-crop weeds and insects at four hybrid willow clonal trial field sites located throughout Saskatchewan.

Chemical* (Brand Name)	**Active Ingredient**	**Rate** (L/ha)	**Cost** ($/ha)	**Target Pest**
Goal 2XL	Oxyfluorfen	4.0	300.00	Broadleaf weeds
Lorox	Linuron	4.5	118.00	Annual weeds
Pardner	Bromoxynil	0.5	8.97	Annual weeds
Poast Ultra	Sethoxydim	1.1	85.57	Annual weeds
Simadex	Simazine	7.0	115.10	Broadleaves/annual grasses
Weathermax	Glyphosate	2.0	39.00	Broad spectrum weed control
Lontrel	Clopyralid	0.42	68.90	Annual weeds
Treflan	Trifluralin	5.25	48.83	Broadleaves/annual grasses
Sencor	Metribuzin	0.3**	22.14	Broadleaves/annual grasses
Decis	Deltamethrin	72.0	6.10	Insecticide

*Some of these chemicals are currently not registered for use on willow crops.
** kg/ha

has to be exercised as this chemical cannot touch any part of the willow that is actively growing or damage to the willow plant will result. If any insect damage is noted in the growing season, an application of insecticide will be required. Extreme caution must always be used when using any of the suggested chemicals on willow crops and always read and follow label directions.

3.1.3 Experimental Design

In order to assess the suitability of six hybrid willow clones grown for use as a biomass energy crop in Saskatchewan, a randomized block design (n=4) was used at each of the four clonal trial sites. The six different hybrid willow clones tested were: Allegany *(Salix purpurea)*, Canastota *(Salix sachalinensis* x *miyabeana)*, Fish Creek *(Salix purpurea)*, Sherburne *(Salix sachalinensis* x *miyabeana)*, SX61 (*Salix sachalinensis*), and SX 64 (*Salix miyabeana*). Briefly, each clonal plot (6.9 x 8.9 m) consisted of 78 plants (three double-rows of 13 plants/row), with spacings of 1.5 m between the double-rows, 76 cm between rows within the double-row, and 60 cm between plants within the double-row (the standard design developed in Sweden), resulting in a planting density of approximately 14,376 plants/ha (Figure 4). In order to prevent edge effects, measurements were taken in the centre 2.3 x 5.5 m area of each clonal plot and consisted of 18 plants (Figure 4).

The plantation should be designed to maximize space but still allow room for equipment that will be required for periodic weed control. Row spacing in between double rows should be 1.5 to 2 metres in order to allow for a variety of small equipment between the rows including small tractors, ATV's, disks, sprayers, cultivators, etc. Inadequate space for equipment will result in the need for manual hand-weeding and this could be an overwhelming task depending on the size of the plantation. The most critical period of moisture availability undoubtedly is shortly after planting and in the spring of 2007 there was excellent stored soil moisture conditions at all sites, along with timely rainfall into late June.

3.1.4 Sampling Protocols

3.1.4.1 Environmental Data

Each site was equipped with an extensive suite of data logging equipment (Campbell Scientific, Inc., Edmonton, AB) for measuring environmental conditions throughout the study (Figure 5). These included: soil temperature (0-10, 10-20, 20-30, 30-50, and 50-70 cm depths), air temperature, rainfall, photosynthetically active radiation, relative humidity, and wind speed. Collecting such detailed environmental data allows for adequate characterization of site conditions, which will be invaluable when interpreting any differences in establishment and growth among the clones at each site as well as any measured differences in clonal performance among the sites.

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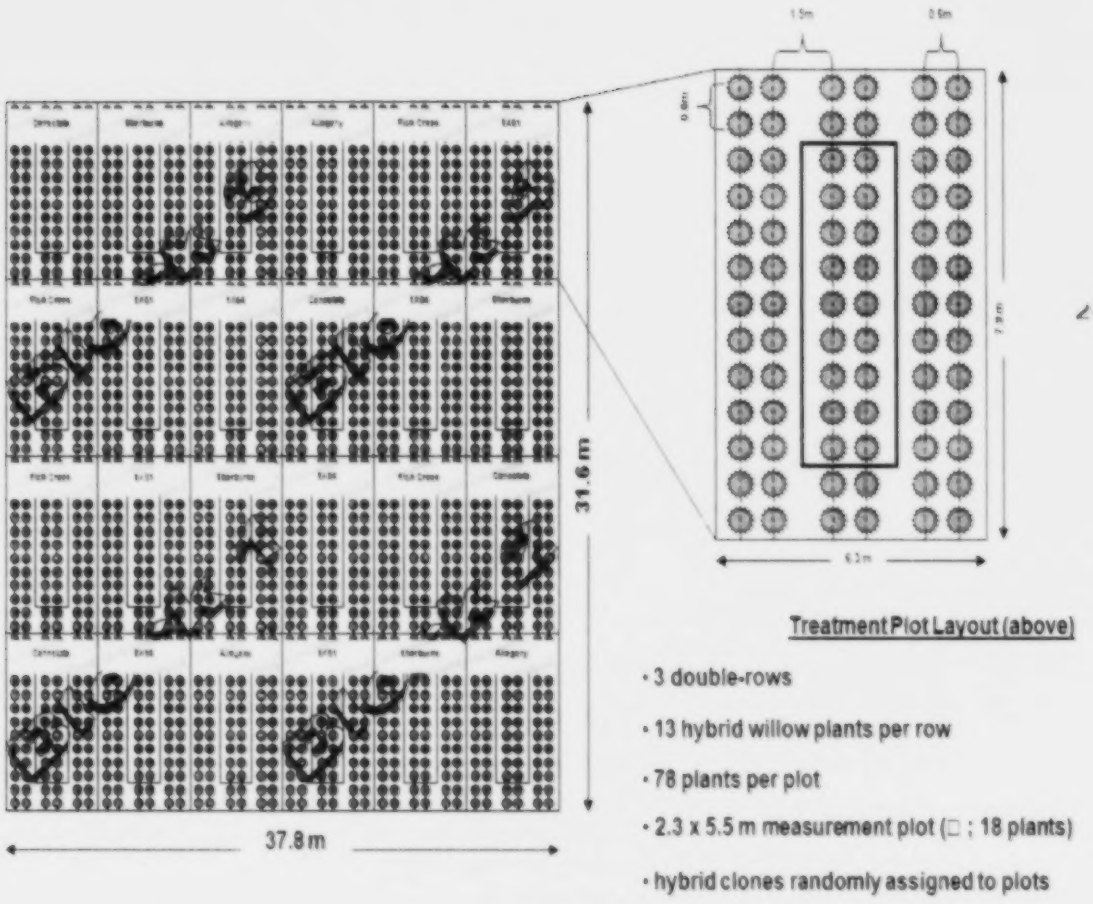
31.6 m
37.8 m
Treatment Plot Layout (above)
• 3 double-rows
• 13 hybrid willow plants per row
• 78 plants per plot
• 2.3 x 5.5 m measurement plot (□ ; 18 plants)
• hybrid clones randomly assigned to plots

Figure 4. Experimental design used for willow clonal trial at Estevan location

Figure 5. Data logger equipment used for environmental monitoring at each site

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3.1.4.2 Relative Emergence, Survival, and Above-ground Biomass of Hybrid Willow

After establishing the four plantations, the diameters of planted cuttings were recorded as well as depth of planted cutting, for correlation with subsequent emergence rates, survival, and above-ground biomass parameters to determine if there is a relationship between them (Figure 6). Emergence among the different clones was assessed qualitatively by simply observing the timing of bud burst of the dormant cuttings following planting. At the end of each growing season, assessments of plant survival, stem diameter, stem height, stem number (i.e., number of stems per stool), and stool biomass production were completed. These measurements were taken sometime after leaf senescence and growth cessation, but prior to bud burst the following spring. In order to help quantify relative differences in cold hardiness among willow clones, percent dieback was assessed following bud break every spring of the rotation, by measuring the average height difference between the living and dead stem tissues on each stool (Figure 7).

Figure 6. Measuring rates of emergence, height, and calliper diameter of hybrid willow clones

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Figure 7. Winter damage observed with the willow clone "Charlie" from an unrelated study

3.1.4.3 Selected Physiological Characteristics of Hybrid Willow

To help explain the measured differences in productivity among the hybrid willow clones out in the field, some different physiological characteristics that may play an important role in influencing the clonal trial field study were investigated. In other words, there may be underlying mechanisms allowing certain clones to outperform others *in situ* within a plantation setting. Given the underlying control of foliar characteristics on subsequent biomass production, it is important to quantify differences among clones that may influence productivity and, therefore, final harvest biomass. In particular, total leaf area (Verwijst and Telenius, 1999), specific leaf area ($cm^2\ g^{-1}$; Tharakan et al., 2005), nutrient resorption efficiency (% of nutrients resorbed from senescing leaves; Yuan et al., 2005), nutrient resorption proficiency (the nutrient concentration (mg/cm^2 in senescing leaves; Killingbeck, 1996), nutrient use efficiency ($g\ g^{-1}$; Vitousek, 1982), and water-use efficiency (i.e., $\Delta^{13}C/^{12}C$; Le Roux-Swarthout et al, 2001), among clones was assessed every year of the rotation at each site (currently, only the 2008 growing season data are available). Leaf sampling was carried out either in mid- to late-September, when the average photoperiod and daytime temperatures are in decline, or in early November to collect senescing leaves.

3.1.4.4 Soil Nutrient Analyses

At each site, three soil cores per plot were collected with an auger, separated into 10 cm depth increments to 60 cm, and composited. All soil samples will be analyzed for N (NO_3^--N and NH_4^+-N), P, K, S, Ca, Mg, and Na. Additionally, Plant Root Simulator™-probes (Figure 8; Western Ag Innovations

Inc., Saskatoon, SK). Due to funding constraints, both the traditional soil testing and the use of the PRS™-probes to measure soil nutrient availability were only carried out in the first growing season.

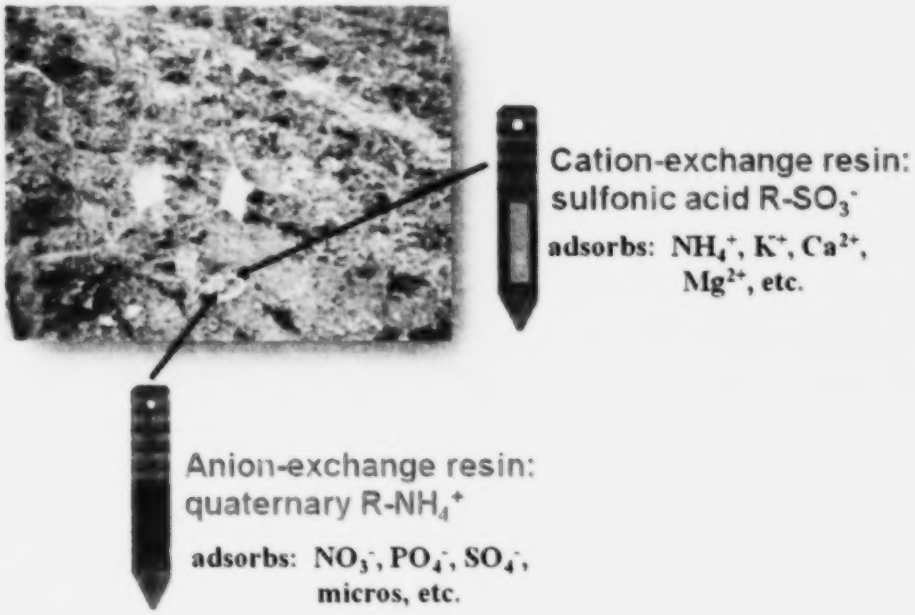

Figure 8. Plant Root Simulator (PRS)™-probes measuring soil nutrient dynamics in situ

3.1.4.5 Non-destructive Techniques for Estimating Above-ground Willow Biomass

Considering that harvesting operations are the greatest single cost incurred with short-rotation willow production systems (Heller et al., 2003, 2004; Keoleian and Volk, 2005; Spitzley and Keoleian, 2005; Tharakan et al., 2005), it is imperative for farmers to optimize the timing of harvest, based on accurate estimations of current yield, for supporting the greatest economical return on investment. Additionally, monitoring annual production rates will be invaluable for management decisions prior to harvest, such as fertilizer amendments. The conventional non-destructive technique is allometry – defined by a simple empirical relationship between size and mass, which involves calibrating measured stem diameter (at a specified height) with subsequently harvested biomass (Figure 9a; Heinsoo et al., 2002; Nordh and Verwijst, 2004; Arevalo et al., 2007). Currently, this is the industry standard with which all other approaches should be compared. However, manually collecting above-ground samples for biomass estimates can be time consuming, costly, susceptible to subjective errors, and inherently

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Figure 9. Estimating above-ground willow biomass using an allometric technique (a) and a LAI-2000 Plant Canopy Analyzer to measure the 'gap fraction' (i.e., fraction of the sky visible from beneath canopy) corresponding to five sensor rings centred on different zenithal angles (b).

destructive. As such, there remains a need to develop a mensurative technique for estimating willow biomass, having not only the accuracy of allometry, but also non-destructively yielding quick and economical data.

A novel alternative approach to allometry proposed in this study involves using the LAI-2000 Plant Canopy Analyzer (LI-COR Inc., Lincoln, NE; Figure 9b) to measure the 'gap fraction', which is the fraction of the sky visible from beneath the canopy, by quantifying the fraction of sky that is blocked by foliage, branches, or stems (i.e., degree of canopy openness; Welles and Norman, 1991; LI-COR, 1992; Machado and Reich, 1999) assessed at five different angles relative to the zenith concurrently, using a "fish-eye" 148° field-of-view optical sensor (LI-COR, 1992; Figure 9b). By measuring the gap fraction of non-photosynthetic woody material, the Plant Canopy Analyzer is, therefore, essentially providing a measure of 'Stem Area Index' (SAI), which can be calibrated with harvested biomass. Given that *in situ* observations clearly indicating the effect of variable above-ground willow biomass on variances in transmitted radiation at ground level (Figure 10), it is hypothesized that the Plant Canopy Analyzer will provide accurate and precise estimates of harvestable willow biomass and, thus, serve as an effective alternative to conventional allometry for providing a fast and reliable indirect measure of willow plantation productivity.

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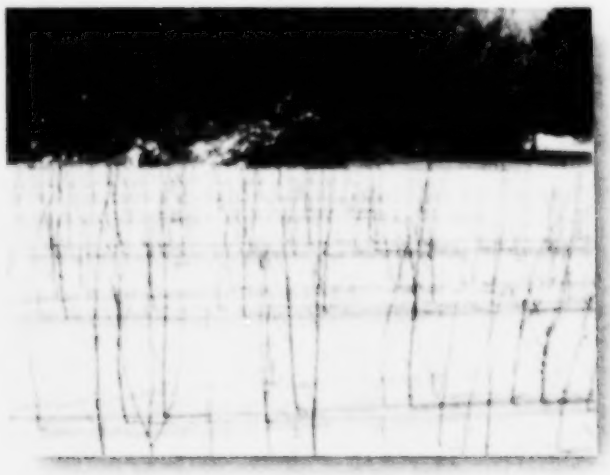

Figure 10. The effect of willow canopy light interception on the fraction of transmitted radiation to the snow surface. Note the marked difference in light levels within rows and between rows, despite the relatively sparse one-year-old willow stems.

Briefly, three different sampling scales (between-row, within-row, and single plant) were used to collect SAI measurements using the Plant Canopy Analyzer (Figure 11). All three sampling schemes involve placing the sensor near the soil surface; using both a 45° and 90° view cap (consisting of a 315° and 270° opaque mask, respectively) to restrict the azimuthal range of the sensor – necessary to not only prevent light not transmitted through the canopy from influencing the measurements (common concern with discontinuous row crops), but also to obscure the operator from the sensor; one above-canopy measurement was taken for every four below-canopy measurements (in the same azimuthal direction) to allow the Plant Canopy Analyzer to determine the fraction of diffuse incident radiation passing through the willow canopy – required for calculating the SAI of the plot; and finally, taking measurements under diffuse sky conditions (i.e., overcast, before sunrise, or after sunset) in order to avoid direct sunlight and/or light scattering within the canopy from influencing the readings. If these were operational-scale plantations, then these sampling schemes would be randomly located within the plantation; however, in view of its small research-scale plot size, each sampling scheme was systematically set up to sample the entire triple-row bed, while avoiding possible edge effects (Figure 11). For each sampling scheme, SAI was calculated based on a total of 16 below-canopy and four corresponding above-canopy measurements within each plot, and the SAI values were correlated with the corresponding willow biomass that was subsequently harvested, dried at 65 °C to a constant weight, and weighed.

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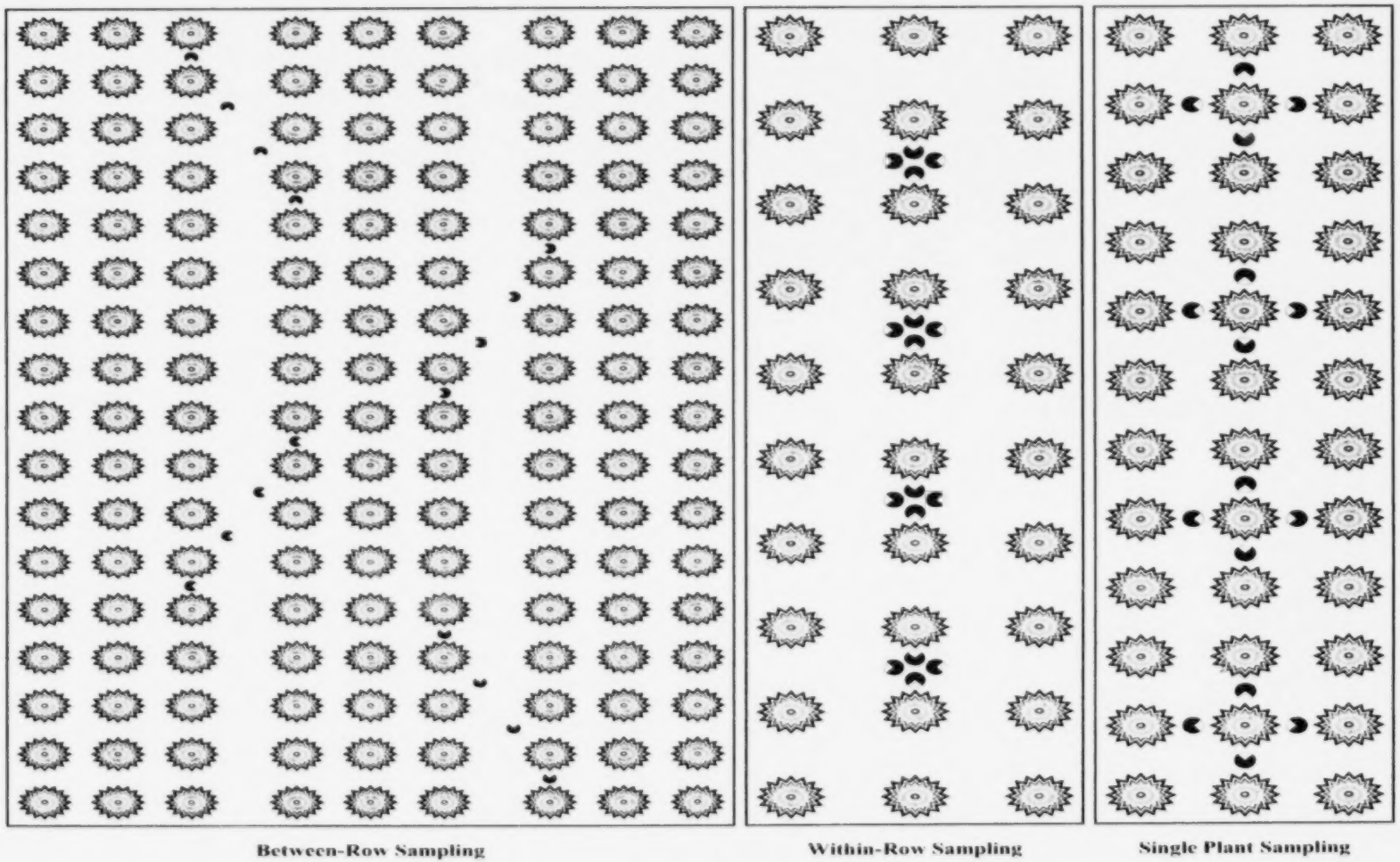

Figure 11. Placement of LI-COR Plant Canopy Analyzer (with 90° view cap indicated by white fraction of circle), at varying sampling scales, to measure gap fraction for correlation with harvested biomass within short-rotation willow plantations.

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3.2 Nitrogen Fertilization Trial

3.2.1 Study Sites

Plantations for fertilization trials were established in Prince Albert in the Boreal Forest Transition Ecozone and in Saskatoon in the Moist Mixed Grassland Ecozone. The Prince Albert site (Figures 12 and 13) is situated at a tree nursery operated by the Pacific Regeneration Technologies Inc. (PRT). The nursery is located approximately 15 km north of Prince Albert (UTM 12U E0448501.4, N5912029.0) at an elevation of 513 m. The dominant soils in the area are Orthic Black Chernozems on the sandy fluvial materials of the Meota Association (Anderson et al., 1997). A soil pit was dug at the site and was classified as an Orthic Black Chernozem. The nursery has been used for growing conifer trees, mainly white spruce, since it was taken over by the PRT in 1997 (Van Eerden, 2002). Prior to 1997, the nursery was managed by the Government of Saskatchewan. Under the management of the PRT, herbicides and fertilizers have not been applied to the research plot used in this trial.

The Saskatoon site (Figure 14) is located on the University of Saskatchewan campus (UTM 12U E0389931.8, N5776381.7). The site has an elevation of 496 m and the soils are of the Sutherland Association. A soil pit was dug on the research site and was classified as an Orthic Vertisol. Past management included continuous cereal production, with barley grown the past three years. In 2006, a portion of the site was given to the Centre for Northern Agroforestry and Afforestation and is currently being utilized for bioenergy production. The plantation in this study used a section of land that had been fallowed for the previous three years. Glyphosate (Monsanto Roundup Weathermax; active ingredient: N-(physphonomethyl) glycine) has occasionally been applied to the area to control weeds.

3.2.2 Experimental Design

Planting material was collected from the pre-established 2006 and 2007 willow plantations in Saskatoon as well as from the Prairie Farm Rehabilitation Administration (PFRA) Shelterbelt Centre in Indian Head, Saskatchewan. Cuttings of 15 cm were made from the Saskatoon material and were kept frozen with the PFRA material at -4°C until two days before planting. The cuttings were thawed at room temperature for 24 hours and soaked in water for 24 hours (Keoleian and Volk, 2005) before they were suitable for planting. The Saskatoon site includes the State University of New York - College of Environmental Science and Forestry (SUNY-ESF) clones, Tully Champion, Saratoga and Marcy, the Canadian Forest Service (CFS) clone, India and a native Saskatchewan clone, *Salix discolour* from the PFRA (Table 3). Due to a restricted quantity of planting material from the PFRA, the Prince Albert

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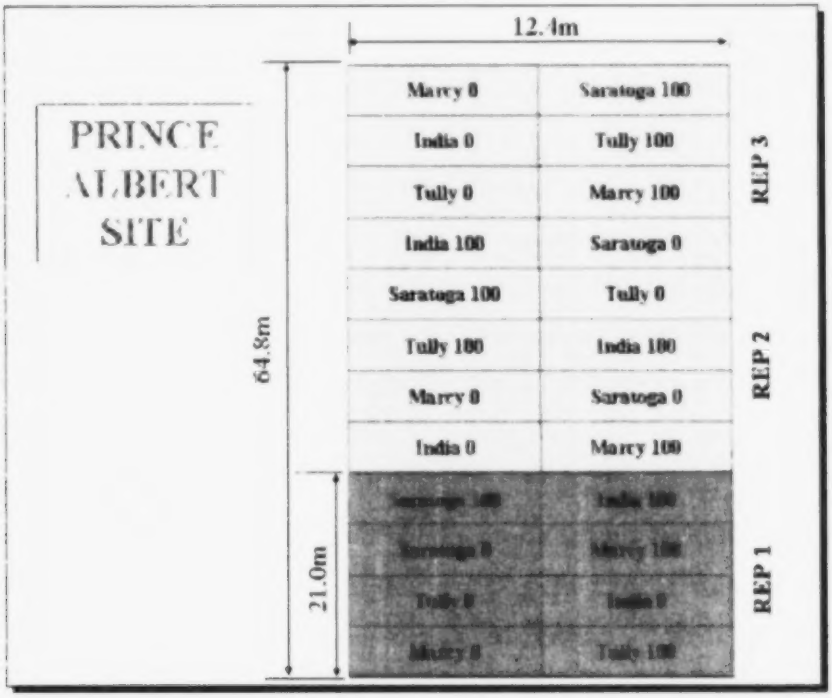

Figure 12. Map of the Prince Albert hybrid willow fertilization trial established in 2008.

Figure 13. Prince Albert fertilization trial in August 2009.

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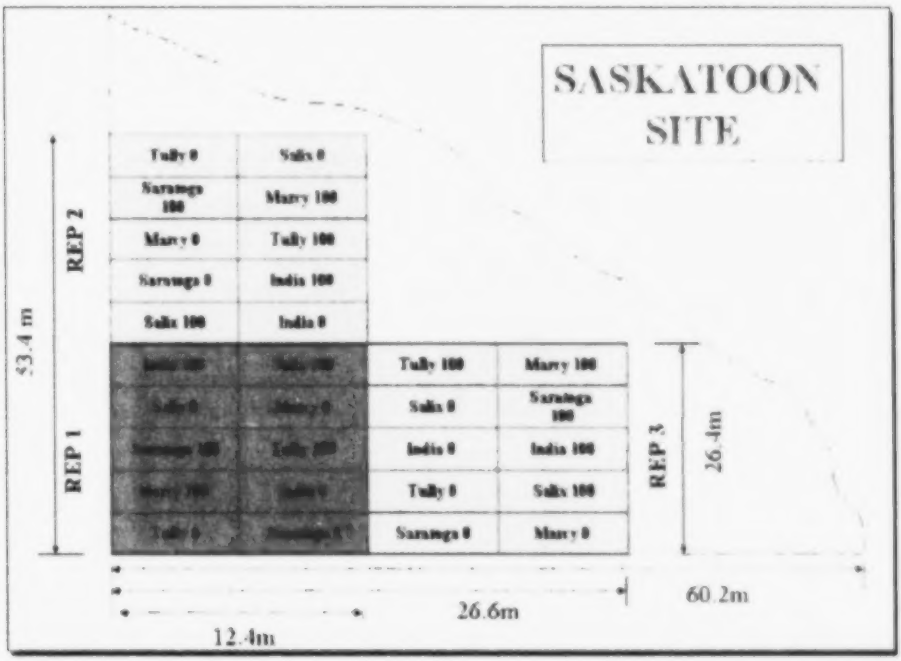

Figure 14. Map of the Saskatoon hybrid willow fertilization trial established in 2008.

Table 3. Properties of willow clones used in the fertilization study.

Clone	Parentage	Gender	Origin
Saratoga	*Salix purpurea x S. miyabeana*	F	SUNY-ESF
Marcy	*S. sachalinensis x S. miyabeana*	F	SUNY-ESF
Tully Champion	*S. viminalis x S. miyabeana*	F	SUNY-ESF
India	*SV1: S. dasyclados*	F	CFS
Salix	*S. discolor*		PFRA

site included only Tully Champion, Saratoga, Marcy and India (*Salix discolour* will not be a part of this site). Due to poor establishment, the Saskatoon research site was not used in the remainder of the study. Only Prince Albert was used to assess N fertilizer response.

Plots were set up according to the Swedish design (Figure 15) which is organized in a three-double row orientation. There are nine trees in each individual row for a total of 54 trees per plot. The outermost rows in each treatment were not be used for measurements in order to avoid border effects.

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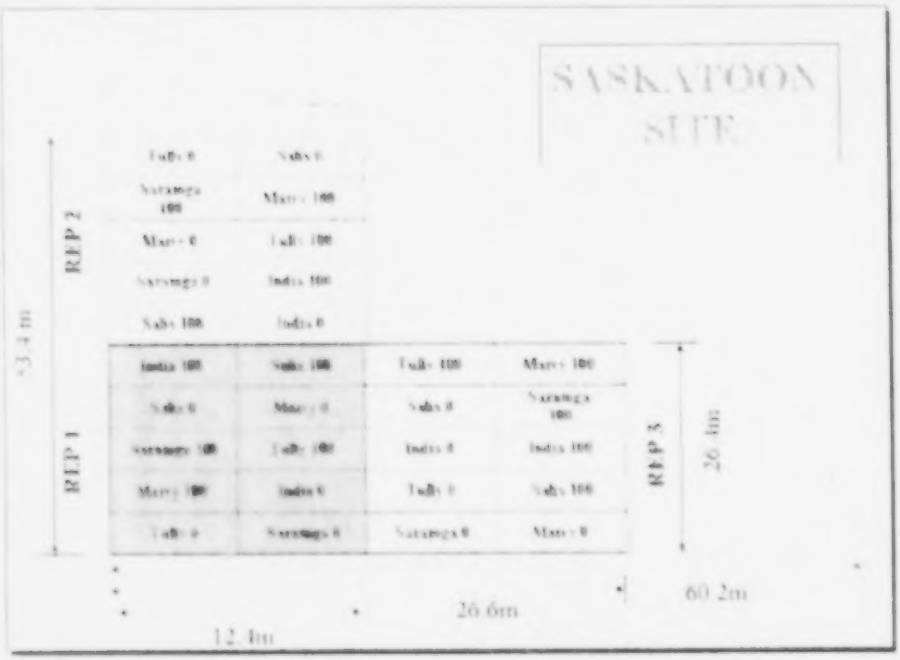

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Salix	*S. discolor*		PFRA

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thus only the ten middle trees will be considered as measurement trees. There were two treatments applied to each clone (0 and 100 kg N ha^{-1}). Each treatment was replicated three times for each clone at both sites. Prior to planting in June of 2008 (Figure 16), each site was rotor-tilled to ensure a satisfactory planting medium. Goal 2XL (Dow AgroSciences; active ingredient: oxyfluorfen) herbicide was applied to both research sites at a rate of 4 L ha^{-1} immediately after planting (Figure 16). In July, substantial emergence had occurred at the Prince Albert site, while little emergence was seen in Saskatoon (possibly drought); hence, the study was not continued. At the end of the growing season, the Saskatoon had a visual survival rate of ~10-20% and the literature states that a survival of less ≤ 80% is not economically beneficial. For this reason, the remainder of the fertilization trial included only the Prince Albert Site. In July, the Prince Albert site was broadcast fertilized with ammonium nitrate at rates of 0 and 100 kg N ha^{-1}. On the same day, a solution of deionized water and 10% enriched double labelled ammonium nitrate ($^{15}NH_4{}^{15}NO_3$; Cambridge Isotope Laboratory) water was applied to two non-measurement trees per plot (Figure 17). Each ^{15}N tree was encased in a 30 x 30 cm corrugated plastic box and covered to ensure that they were not affected by the hand broadcasting of the granular fertilizer. The ^{15}N solution was applied to the inner area of the30 x 30 cm box at a rate of 5 kg N/ha. To maintain a fertilization rate of 100 kg N/ha, 95 kg N/ha of granular ammonium nitrate was applied to the inner area of the box.

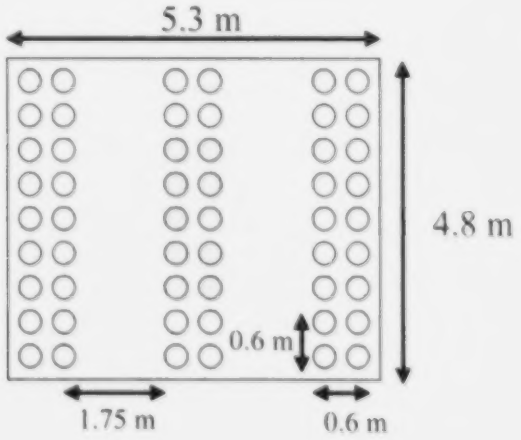

Figure 15. Swedish plot design of a three-double row orientation with the highlighted circles being measurement trees.

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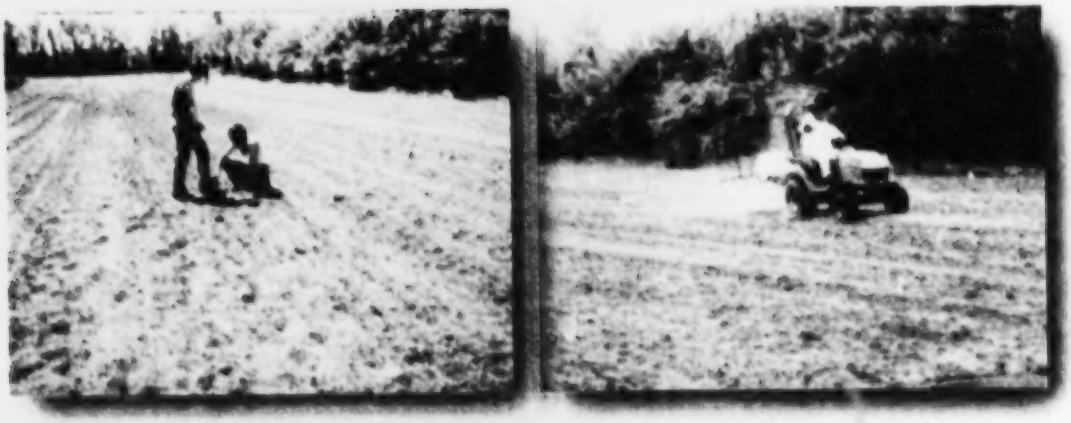

Figure 16. Planting (left) and spraying (right) the Prince Albert fertilization trial.

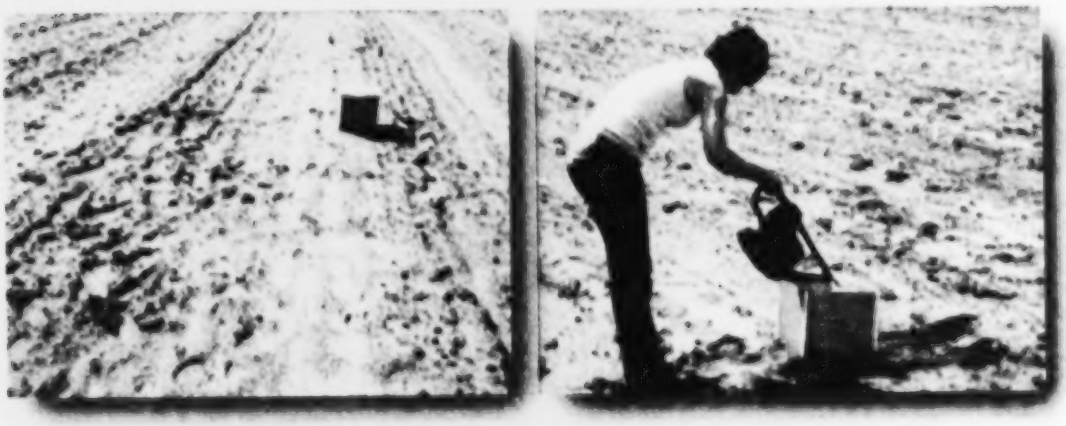

Figure 17. The fertilization of Prince Albert willow plantation using hand broadcasted ammonium nitrate (left) and double labeled ^{15}N labeling (right).

3.2.3 Sampling Protocol

Soil samples were collected throughout the study to monitor nutrient levels. Preliminary soil samples were taken within each plot on the day of planting from 0-30 cm. Soil samples were also collected within each plot a week after fertilization application and at the end of the first and second growing seasons at depths of 0-10, 10-20 and 20-30 cm. All soil samples were taken with a JMC Backsaver Soil Sampler (Clements Associates Inc., Newton, I.A.) from three locations within the tree rows. Biomass from the measurement trees was obtained from one tree per plot in September of 2009. The shoots and leaves were air dried and measured for oven dried yields (OD tones ha^{-1}). Non-destructive measurements were made at the end of the first growing season and at the beginning of each month throughout the second growing season (June, July, August and September). These

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measurements included the number of shoots, the height of the tallest shoot (cm) and the diameter of the tallest shoot at 30 cm above the soil surface.

3.2.4 ^{15}N Sampling Protocol

At the end of each growing season, one ^{15}N fertilized tree from each plot was harvested (Figures 18 and 19). The trees were divided into leaves, shoots and roots to determine where the ^{15}N is accumulated and thus which plant part benefits most from the application of the N fertilization. Soil samples were collected from within the 30 x 30 cm area around each ^{15}N labelled tree at depths of 0-10, 10-20 and 20-30 cm to quantify and locate the vertical movement of N through the soil profile. The plant and soil samples were fine ground and analyzed for %N and $\%^{15}N$ excess on an isotopic ratio mass spectrometer (RoboPrep Sample Converter interfaced with a TracerMass Stable Isotope Detector, Europa Scientific, Crewe, England) in the Department of Soil Science, University of Saskatchewan.

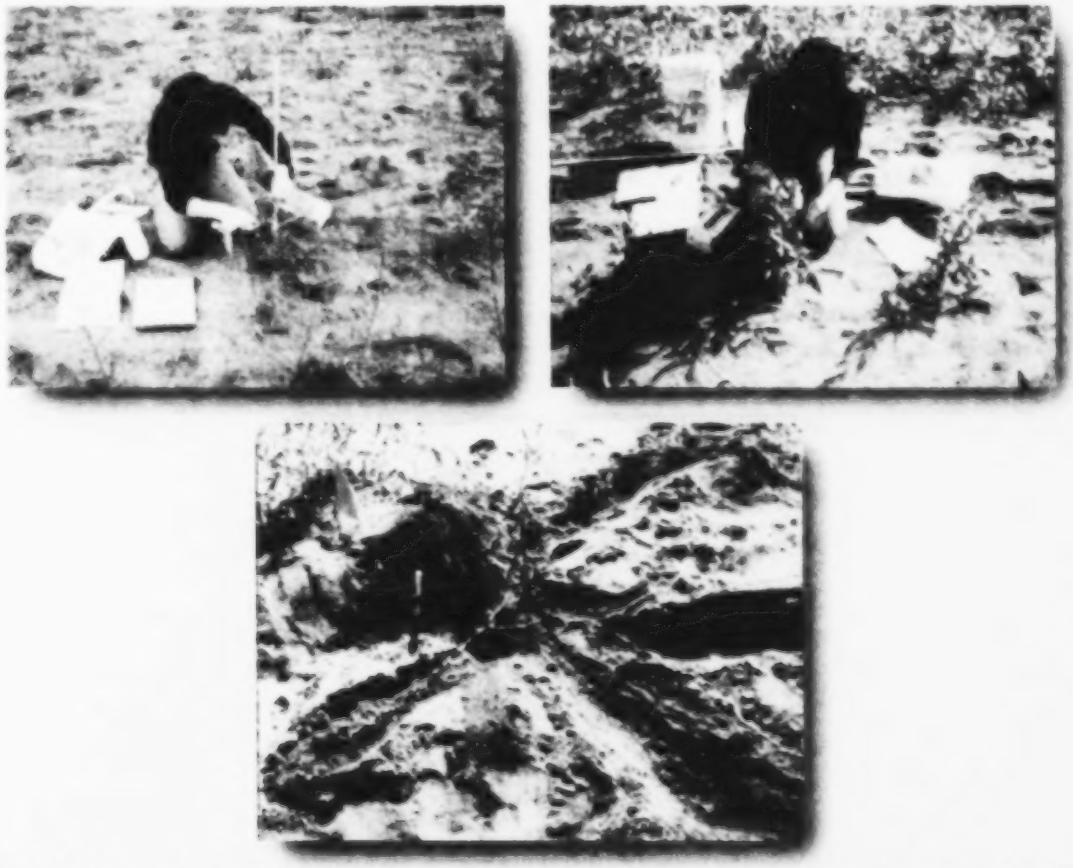

Figure 18. Measuring tree height and stem diameter (top left), collecting foliar samples of the ^{15}N labeled trees (top right), and root system excavavtion (below).

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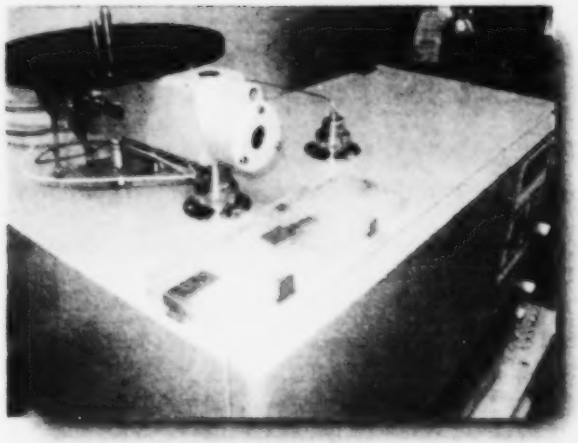

Figure 19. ^{15}N samples awaiting analysis on the isotopic ratio mass spectrometer.

3.2.5 Soil Nutrient Analysis

Soil samples were analyzed for organic and inorganic carbon content using a LECO C632 Carbon Determinator (Leco Corporation, St. Joseph, M.I.). Extractable P was measured using a modified Kelowna extraction (Qian et al., 1994) followed by colorimetric analysis on a Technicon Auto Analyzer (Pulse Instrumentation Ltd., Saskatoon, S.K.). Nitrogen content was analysed using a KCl extraction and a Technicon Auto Analyzer. Extractable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) were measured using an ammonium acetate extraction (Simard, 1993) followed by analysis using an atomic absorption spectroscoper. Soil samples were evaluated for pH and EC using 2:1 water to soil suspension (Hendershot et al., 1993) and analyzed using a Beckman 50 pH Meter (Beckman Coulter, Fullerton, C.A.) and a Horiba ES-12 Conductivity Meter (Horiba, Ltd., Kyoto, Japan), respectively.

3.2.6 Foliar Nutrient Analysis

Foliar samples were obtained before leaf senescence. Five leaves from each measurement tree were collected and analyzed for total N and P content using a sulphuric acid digest (Thomas et al., 1967) followed by analysis on a Technicon Auto Analyzer. The sulphuric acid digests solutions were also used to measure Ca, Mg, Na and K using an atomic adsorption spectrometer.

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3.2.7 Monitoring Environmental Conditions

At each site, environmental data of pre-established plantations has been monitored using various Campbell Scientific instrumentation (Campbell Scientific Inc., Logan, U.T.). This includes air temperature, wind speed, rainfall, relative humidity and incoming solar radiation. Soil conditions have also been observed under the clone SX64 (SUNY-ESF) looking at soil moisture at 0-10, 10-20-, 20-30, 30-45 and 45-60 cm depths and soil temperature at 10, 20, 30, 40, 50, 60 and 70 cm depths.

3.3 Growth Chamber Fertilization Trial

Due to restrictions in the amount of land available for the field fertilization study, more treatments were observed in a controlled environment growth chamber study between January and April 2009. Three clones from the field trial were chosen for this study based on their growth productivity during the first year of the field clonal trial. Planting material was collected from the Saskatoon clonal trial in January 2009 when the shrubs were still dormant and the material was cut into 15 cm long cuttings. Prior to planting, the cuttings were thawed to room temperature for 24 hours and allowed to soak in water for 24 hours. Soil was collected from current Saskatoon and Prince Albert research sites and was air dried and sieved (2 mm) for consistency (Table 4). A single willow cutting was planted in the centre of a 15 cm diameter pot of soil. Five fertilization treatments were applied to the three clones; inorganic N fertilizer at rates of 50, 100 and 200 kg N ha^{-1}, composted cattle manure at 100 kg N ha^{-1} as well as an unfertilized control treatment. Fertilization treatments were replicated four times for each clone and were carried out on the two soils. Pots were placed in an indoor growth chamber at 25 °C with a 18:6 hour light:dark photoperiod and were hand watered to field capacity every other day.

Table 4. Mean preliminary soil nutrient contents for Saskatoon and Prince Albert field and growth chamber fertilization trials.

Site	Soil Nutrient		
	NO_3^-	NH_4^+	PO_4^-
Saskatoon	0.9510a†	2.079a	0.6795b
Prince Albert	0.2509b	1.614b	10.56a

† Means within a column followed by the same letter are not significantly different ($P > 0.05$) using LSD.

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Throughout the 90 day experimental period, on arbitrarily selected days (20, 28, 37, 40, 47, 55, 64, 72, 81 and 90) the number of shoots, height of the tallest shoot and the presence of disease was recorded for each pot. On the final day, trees were harvested and divided into leaves, shoots and roots and air dried to measure biomass. Foliar samples will be digested using a sulphuric acid digest (Thomas et al., 1967) and analyzed on an Auto Analyzer for total N and P contents. Composite soil samples will be analyzes for N and P contents using KCl (Keenley and Nelson, 1982) and Kelowna (Qian et al., 1994) extractions.

3.4 Fertilization and Irrigation Trial

3.4.1 Experimental Design

This study is being carried out within an existing Canadian Forest Service two-year-old willow plantation, directly adjacent to the Saskatoon clonal trial site. The plantation is a clonal trial with seven different clones of willow arranged in a randomized complete block design, replicated three times, using a 60 x 60 cm spacing within each triple-row bed and 200 cm spacing between beds, resulting in a density of approximately 15,625 stems/ha. Due to insufficient willow material at time of planting, there are unequal numbers of beds among clones (Figure 20). Consequently, only a single bed will be used for the imposed treatments in this study and only with those clones having more than one bed, namely: Charlie (*S. alba* x *S. glatfelteri*) and SV1 (*S. dasyclados*), neither of which are included in the clonal trial.

In the spring of 2008, one bed from each clone were coppiced and will be grown for the standard three-year period before being harvested. A 3 x 3 factorial design of three different rates of both irrigation and fertilizer treatments were imposed on each bed, resulting in a split-split-plot experimental design (i.e., clone as the whole plot factor, irrigation rate as the subplot factor, and fertilizer rate as the sub-subplot factor; Figures 20 and 21). The three irrigation treatments consist of either no additional water added above rainfall or drip irrigation used to maintain the available soil moisture at either *full* (i.e., 80-100 % of available water) or *deficit* (i.e., 50 % of available water) levels, measured using soil moisture probes (Watermark Sensor, Irrometer Company, Inc., Riverside, California) installed within each plot (Spaans and Baker, 1992). A Campbell Scientific CR10x is being used to monitor soil moisture and control irrigation timing (Figure 22). The three fertilization treatments include no fertilizer or fertilizer applied once annually over the three-year rotation either at the recommended rate (Fert Treatment #1) or 2x the recommended rate (Fert Treatment #2). The

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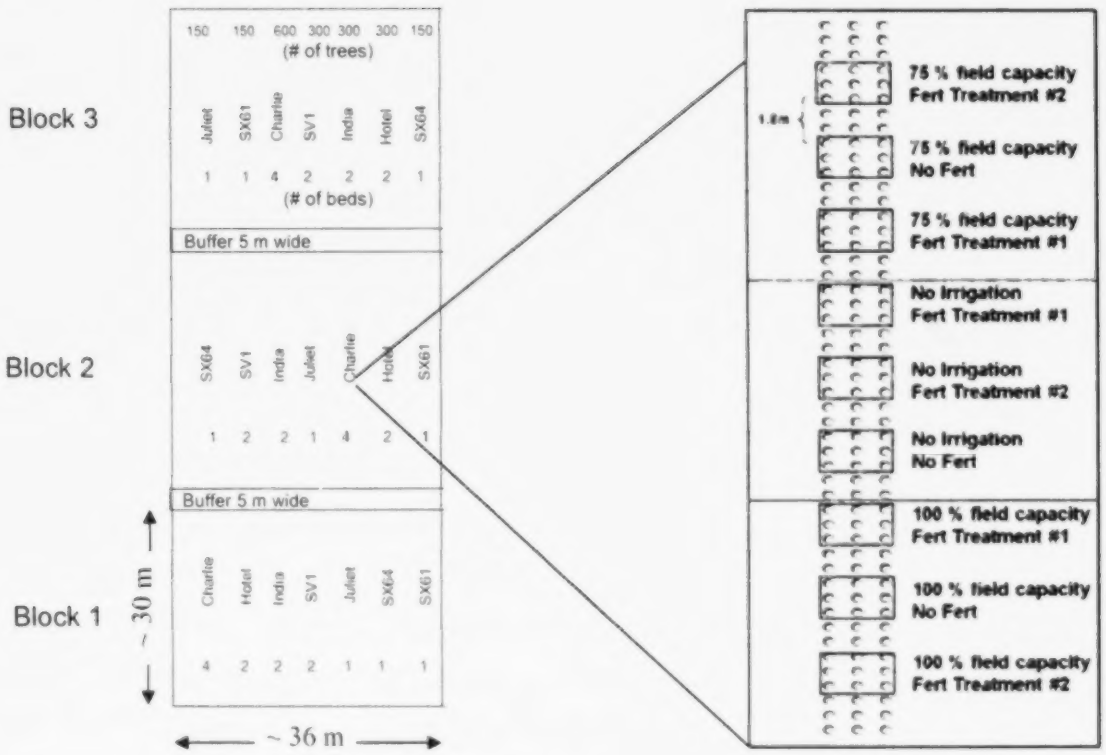

Figure 20. Field study testing the effects of irrigation and fertilizer on willow biomass production.

recommended rate consists of a balanced fertilizer blend of 100:30:80:20 (N:P:K:S) kg/ha, which is intended to not only match hybrid willow growth requirements, but also replenish nutrients exported when harvesting willow with annual biomass production of 15-22 Mg/ha (Perttu, 1993; Danfors, 1998; Adegbidi et al., 2001). The 2x recommended rate is intended to test the upper limit of willow growth response to added fertilizer, when grown on Class 2-3 agricultural soil under optimal moisture conditions, along with quantifying its influence on chemical and physical wood properties at time of harvest. Previous studies report negligible nitrate leaching from heavily fertilized (i.e., up to 240 kg N/ha applied annually) willow plantations after the first growing season with established root systems (Dimitriou and Aronsson, 2004). Consequently, leaching is not expected to be a problem in this study with the 2x recommended fertilizer rate treatment of 200 kg N/ha applied annually, because of its current two-year-old root system and the heavy clay soils at this site. The irrigation and fertilizer treatments were initiated in early July to avoid exacerbating potential late frost damage and also ensure the willow are vigorously growing, in order to increase the fertilizer use efficiency (Abrahamson et al.,

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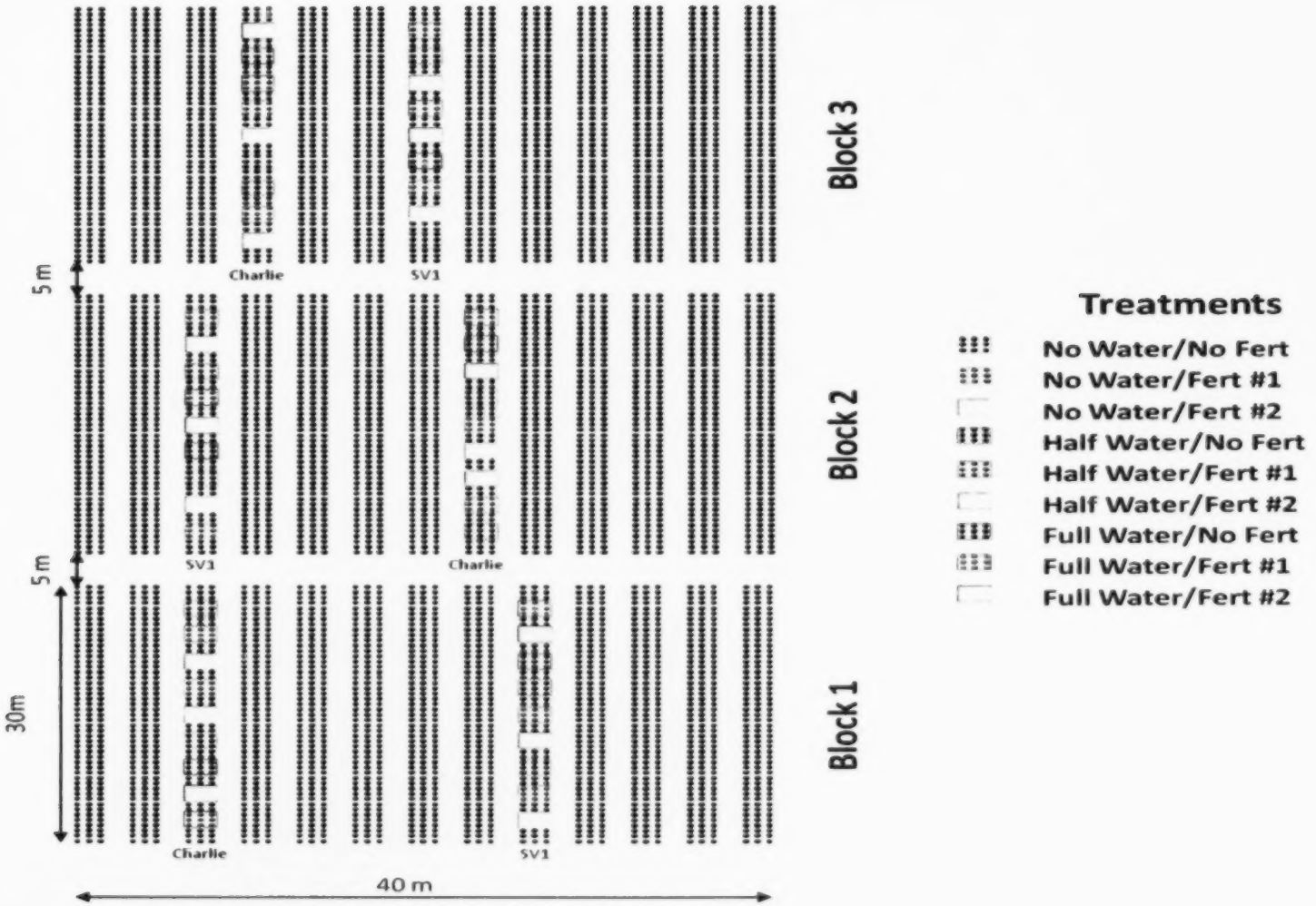

Figure 21. Plot layout of hybrid willow irrigation and fertilizer trial in Saskatoon.

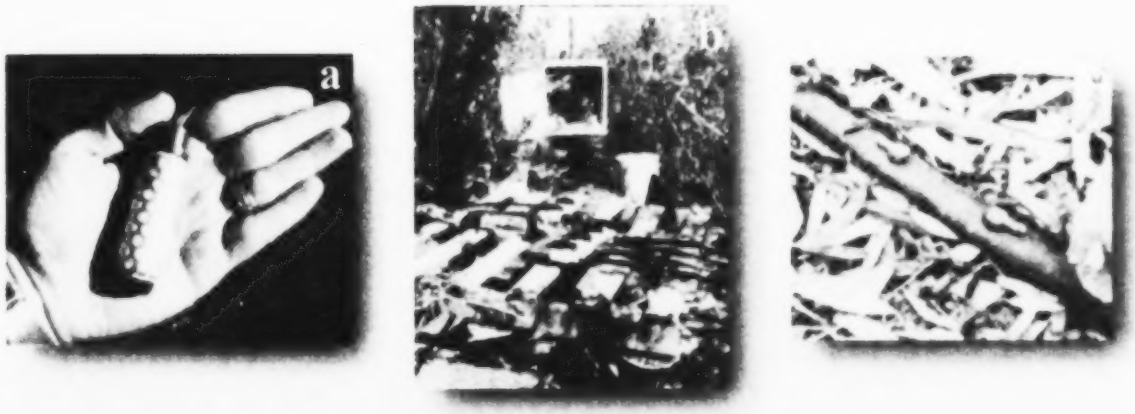

Figure 22. Components of the automated irrigation system: Watermark™ soil moisture sensors (a), irrigation manifold and datalogger (b), and drip line with 0.5 gph pressure-compensating emitters.

2002). Likewise, irrigation will cease at the beginning of September, in order to prepare the willow for a possible early frost episode.

3.4.2 Sampling Protocol

At the end of each growing season, subsamples of leaf and stem tissues within each plot were collected and used to estimate biomass production. Leaf and stem nutrient-use efficiencies, which are based on the ratio of biomass production per unit of nutrient, will also be determined at a later date (Laclau et al., 2000).

3.5 Salinity Tolerance of Native and Exotic Willow

Dryland salinity is a significant agronomic problem across the Canadian prairies (Acton, 1995). According to Eilers et al. (1995), the incidence of salinity can be summarized as follows: i) the majority (62 %) of arable land in the prairies contains less than 1 % saline soil, ii) 36% of the arable land contains 1-15% saline soil, and iii) 2% of the arable land contains more than 15 % saline soil. A number of studies have examined salinity in Saskatchewan soils (Hogg and Henry, 1984; Henry et al., 1985; Keller and Van der Kamp, 1988), but accurate estimates of saline-affected area are difficult to establish due to its large aerial extent and inherent variability, given the ephemeral nature of salts moving through the soil profile. However, it has been estimated that there are approximately 1.6

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million ha (4.1 million acres) of saline soils in Saskatchewan alone (Rennie and Ellis, 1978) and these lands are either being used to grow low return forage crops or have been abandoned altogether. The potential exists, therefore, to make better use of these saline lands by developing them into SRIC willow plantations, which is not only economically positive for the farmer, but also may provide environmental benefits such as precluding the build up of surface salts given willow's water-demanding nature along with promoting increased biodiversity within the agricultural landscape. Additionally, the propensity exists for early adopting farmers to relegate these SRIC willow plantations to any available marginal land (which may be saline), in order to better manage their risk, so it would be prudent to test the salt tolerance of different hybrid willow species from a strictly agronomic perspective. However, no work has been done looking at willow salt tolerance, so the objective of this study was to determine the salt tolerance of a number of exotic and native hybrid willow clones for assessing the potential use of SRIC willow plantations to revitalize these abandoned agricultural lands in Saskatchewan.

For this pot study, Kettlehut Association loam soils were collected in the field from a catena, influenced by toe-slope salinity, containing high concentrations of sulfate salts, which commonly occurs within western Canada (Figure 23). The soils were blended to achieve four salinity levels: non-saline to very slightly saline (0.1 and 1.0 dS/m), slightly saline (2.0 dS/m), and moderately saline (4.0 dS/m). Plant material of 37 different willow clones was collected from one-year-old stools in the spring of 2009 from the Saskatoon plantation (Table 5), sectioned into 15 cm cuttings, and planted in pots. Above- and below-ground biomass were measured after 60 days (Figure 24).

4.0 Results and Discussion

4.1 Hybrid Willow Clonal Trial

4.1.1 Environmental Data

The environmental data collected at each of the four sites over the three years of this study are presented in Appendices B-E. For the most part, the datalogger equipment utilized at each site successfully recorded the desired environmental characteristic at each site, although malfunctions resulted in the loss of some data. When comparing the cumulative growing season conditions (i.e., May-September) and by combining all three years among all four sites (Table 6), it appears that there was minimal variation among the four sites. The smaller total rainfall and photosynthetically active radiation observed at Birch Hills was attributed to a malfunctioning datalogger, which prevented data

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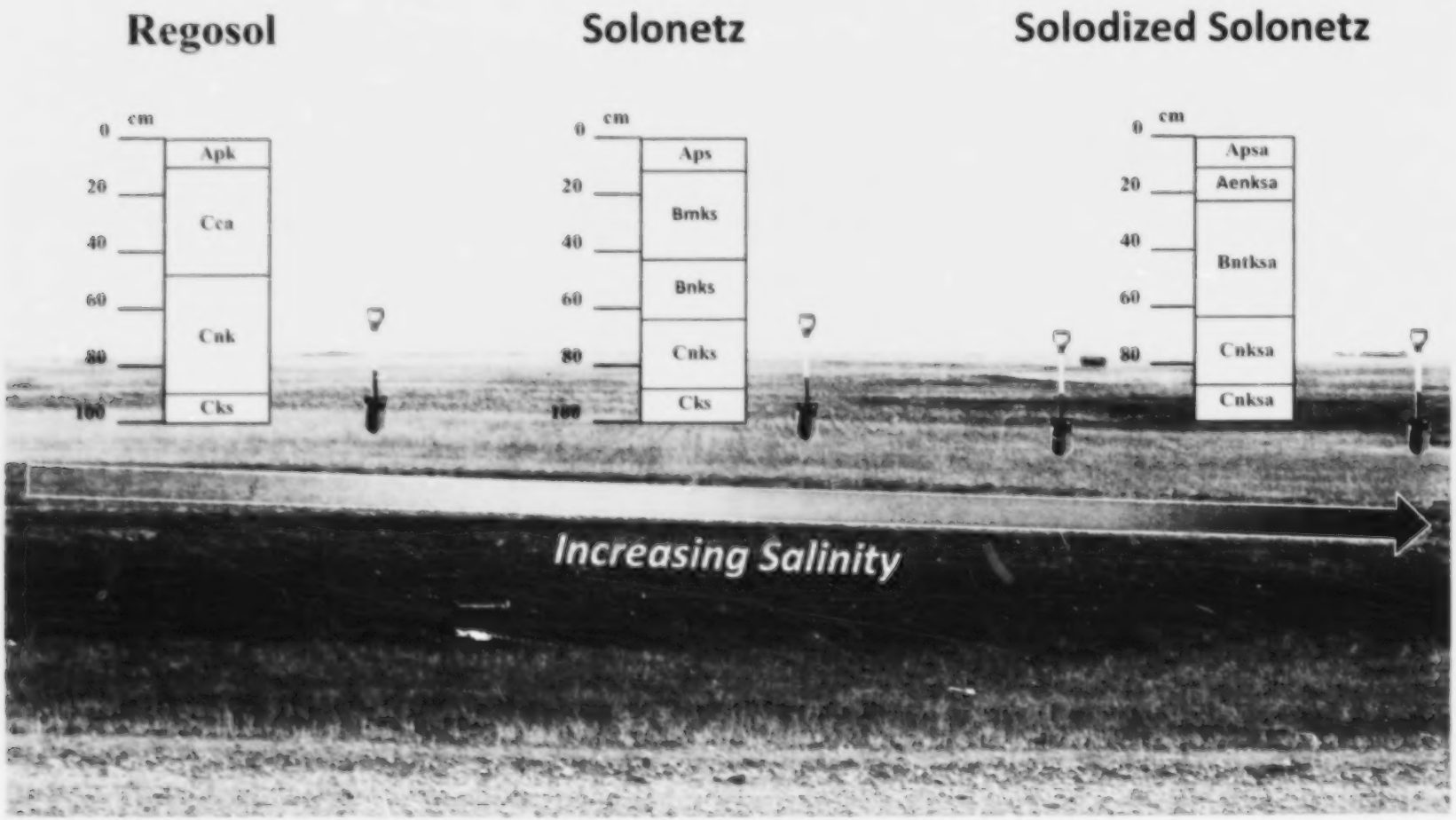

Figure 23. Saline soils were collected at four locations from a hillslope catena, influenced by toe-slope salinity.

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Table 5. Selected shrub willow (*Salix* spp.) clones screened for salt tolerance.

Clone	Species	Sex	Clone	Species	Sex
(1) Allegany	S. purpurea	F	(20) Saratoga	S. purpurea x S. miyabeana	F
(2) Alpha	S. viminalis	F	(21) Saskatoon D3	S. discolor	?
(3) Canastota	S. sachalinensis x S. miyabeana	M	(22) Saskatoon E3	S. eriocephala	?
(4) Charlie	S. alba x S. glatfelteri	?	(23) Sherburne	S. sachalinensis x S. miyabeana	F
(5) Cicero	S. sachalinensis x S. miyabeana	F	(24) SV1	S. dasyclados	F
(6) Fabius	S. viminalis x S. miyabeana	F	(25) SX-61	S. sachalinensis	F
(7) Fish Creek	S. purpurea	M	(26) SX-64	S. miyabeana	M
(8) Hotel	S. purpurea	?	(27) Taberg	S. viminalis x S. miyabeana	F
(9) India	S. dasyclados	M	(28) Truxton	S. viminalis x S. miyabeana	F
(10) Juliet	S. eriocephala	?	(29) Tully Champion	S. viminalis x S. miyabeana	F
(11) Marcy	S. sachalinensis x S. miyabeana	F	(30) Verona	S. viminalis x S. miyabeana	F
(12) Millbrook	S. purpurea x S. miyabeana	F	(31) 94001	S. purpurea	M
(13) Oneida	S. purpurea x S. miyabeana	M	(32) 00X-026-082	S. eriocephala	M
(14) Onecnta	S. purpurea x S. miyabeana	M	(33) 00X-032-094	S. eriocephala	?
(15) Onondaga	S. purpurea	M	(34) 01X-268-015	S. viminalis x (S. sachalinensis x S. miyabeana)	?
(16) Otisco	S. viminalis x S. miyabeana	F	(35) 9837-77	S. eriocephala	F
(17) Owasco	S. viminalis x S. miyabeana	F	(36) 9882-041	S. purpurea	F
(18) S25	S. eriocephala	F	(37) 99208-038	S. viminalis x S. miyabeana	F
(19) S365	S. caprea	F			

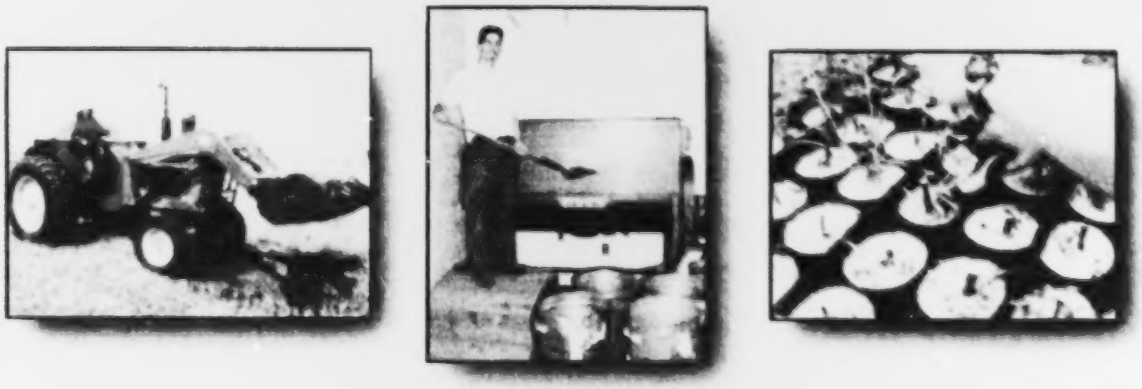

Figure 24. Collecting soil along a saline hillslope catena near Central Butte, SK (a), blending air-dried soils to achieve desired salinity levels (0.1, 1.0, 2.0, and 4.0 dS/m) (b), and assessing willow growth after 60 days (c).

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Table 6. Environmental data collected over three years (2007-2009) at several locations in Saskatchewan.

Site	Total Rain (mm)	Average Relative Humidity (%)	Total PAR $\mu mol/m^2/sec$	Average Air Temperature °C	Average Soil Temperature (0-30 cm) °C
Birch Hills*	332	72	1903	15	15
Estevan	538	65	2833	16	19
PA	516	70	2349	14	17
S'toon	524	62	2712	15	16

* Due to malfunctioning datalogger, only one month of the 2009 growing season is represented.

collection for essentially all of the 2009 growing season. Collecting such detailed environmental data allows for adequate characterisation of site conditions, which typically helps support the interpreting any differences in establishment and growth among the clones at each site, however, it appears that during the three years of this study, differences in climatic conditions may not have influenced plantation productivity as expected.

4.1.2 Relative Emergence, Survival, and Above-ground Biomass of Hybrid Willow

After establishing the plantations in the spring of 2007, an assessment of the emergence of above-ground growth of the planted willow cuttings was carried out at each of the four sites and there was a discernable trend in the rate of emergence among the clones (Table 7), specifically, Canastota > SX61 > Fish Creek > Allegany > Sherburne = SX64. Although all clones had initiated growth within the first two weeks after planting, the risk of a late spring frost is always a possibility given the temperate climate of Saskatchewan, so it is important to identify which clones might be most susceptible given their rapid emergence following planting.

During the first growing season, the primarily concern dealt with assessing different factors that may impact seedling mortality and ultimately plantation success. Despite a large variation in planting stock morphology (Figure 25), planting quality by the volunteer planters (Figure 26), and emergence characteristics among clones (Table 7), it was reassuring to observe high rates of survival (Table 8) and consistent first year biomass (Table 9) for each clone among all sites. There were two instances of increased mortality and reduced productivity during the establishment year due to human

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Table 7. Mean (n=4) rates of emergence of different hybrid willow clones planted at several locations throughout Saskatchewan.

	Site			
Emergence	Birch Hills	Estevan	Prince Albert	Saskatoon
1st	Canastota	SX61	Canastota	Canastota
2nd	SX61	SX64	SX61	SX61
3rd	Allegany	Fish Creek	Fish Creek	Fish Creek
4th	Fish Creek	Canastota	Allegany	Allegany
5th	Sherburne	Sherburne	Sherburne	Sherburne
6th	SX64	Allegany	SX64	SX64

Note: Overall ranking: Canastota > SX61 > Fish Creek > Allegany > Sherburne = SX64

Figure 25. Relationship (n = 96) between diameter of cutting, at time of planting, and height of several two-month old hybrid willow clones.

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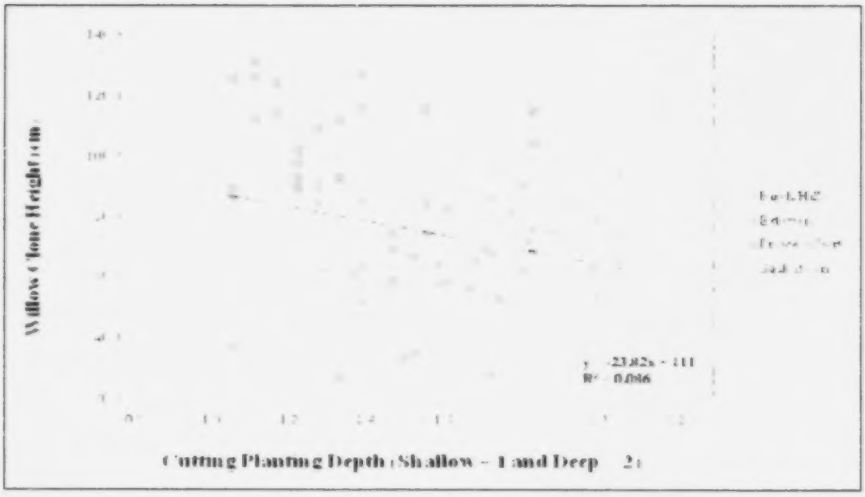

Figure 26. Relationship (n = 96) between planting depth of cutting and height several two-month old hybrid willow clones.

Table 8. Mean (n=4) survival of different hybrid willow clones planted at several locations throughout Saskatchewan.

Site	Willow Clone					
	Allegany	Canastota	Fish Creek	Sherburne	SX61	SX64
Birch Hills	100a*	97a	100a	100a	94a	90ab
Estevan	90a	82b	93a	90a	94a	88ab
Prince Albert	100a	99a	100a	100a	99a	100a
Saskatoon	93a	97a	96a	94a	97a	83b

* Means within a column followed by the same letter are not significantly different ($P > 0.05$) using LSD.

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Table 9. Mean (n=4) pre-coppice establishment year above-ground biomass (kg/ha) of hybrid willow clones planted at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	292a*	474ab	567c**	303ab
Canastota	299a	242b	1318a	248ab
Fish Creek	286a	312ab	832bc	359a
Sherburne	307a	474ab	1221ab	193b
SX-61	251a	593a	1380a	254ab
SX-64	294a	397ab	1123ab	205b

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.
** Clone heavily browsed by deer.

damage from either herbicide drift or trampling during installation of the weather station; needless to say, both were excellent operational lessons. The only other significant reduction in productivity emerging during the early establishment phase occurred with the clone Alleghany at Prince Albert and was due to preferential browsing of this clone by deer, which continues to occur and has significantly impacted the productivity of this clone at this site. Similar with the first growing season prior to coppicing, after two growing seasons post-coppice, it continues to be difficult to discern any productivity trends among the six clones in this study when comparing clone growth rankings among the four sites (Tables 10 and 11). Even when looking at pooled data from all four sites (Figures 27 and 28), no obvious trends among clonal productivity were apparent after two years. There are likely three reasons why this may be so: i) there were significant genotype x environment effects at play that are confounding the data, ii) more time is required (i.e., one more growing seasons before harvest) for productivity differences amongst the clones to become evident, or iii) the genetic yield potential of the different clones is similar. Additionally, it appears that all clones produce less stems, instead concentrating their growth in existing above-ground material (Tables 12 and 13); however, when

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Table 10. Mean (n=4) first-year above-ground biomass (kg/ha) of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	5082a*	6104a	2899b**	1663a
Canastota	3782ab	1386b	4100b	1254a
Fish Creek	2892b	4411ab	3476b	1486a
Sherburne	4972a	3821ab	4675ab	1067a
SX-61	3074b	5626ab	7552a	1064a
SX-64	3350ab	4357ab	5097ab	1007a

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.
** Clone browsed by deer.

Table 11. Mean (n=4) second-year above-ground biomass (kg/ha) of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	13078a*	18205a	8492a**	3426a
Canastota	9628ab	5014a	8768a	3740a
Fish Creek	7760b	15844a	10511a	3335a
Sherburne	12599ab	15567a	9321a	3302a
SX-61	8131ab	19572a	16017a	3098a
SX-64	10396ab	16316a	8894a	3159a

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.
** Clone browsed by deer.

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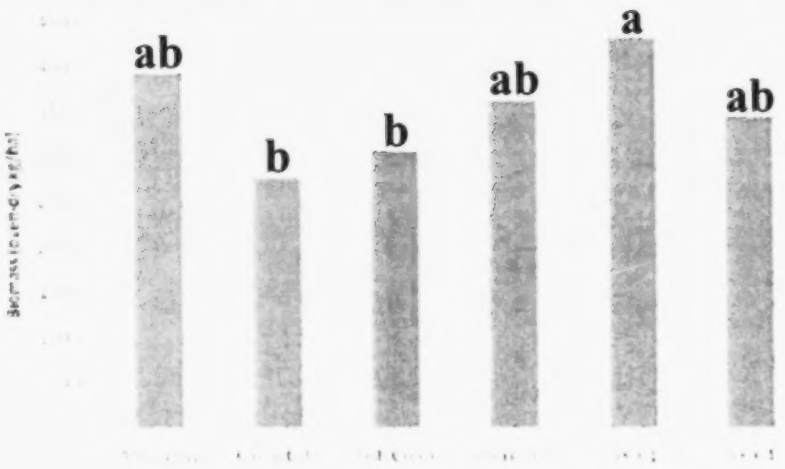

Figure 27. Mean (n=16) above-ground biomass of coppiced hybrid willow clones (averaging all sites) in Saskatchewan after one growing season. For each site, bars with the same letter are not significantly different (P >0.05) using LSD.

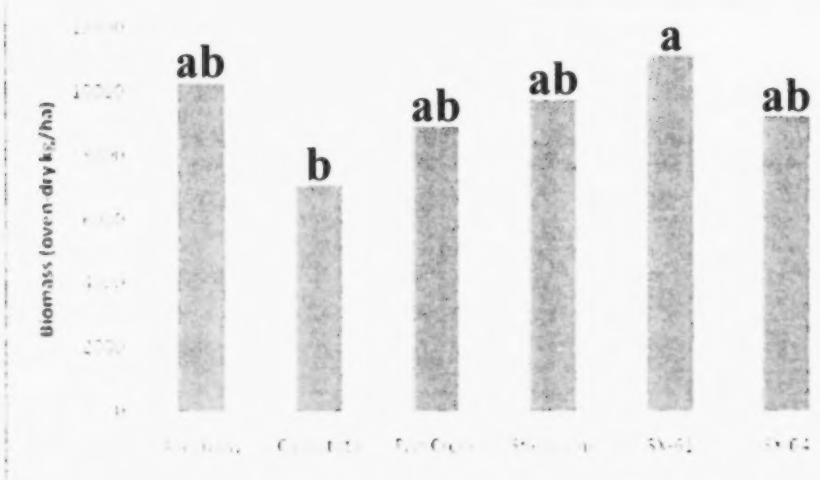

Figure 28. Mean (n=16) above-ground biomass of coppiced hybrid willow clones (averaging all sites) in Saskatchewan after two growing seasons. For each site, bars with the same letter are not significantly different (P >0.05) using LSD.

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Table 12. Mean (n=4) first-year stem density (# stems/ha) of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	257a*	289a	191a	167a
Canastota	123bc	91b	214a	111b
Fish Creek	128bc	162b	238a	101b
Sherburne	143b	178b	244a	104b
SX-61	108bc	220b	225a	96b
SX-64	98c	128b	221a	78b

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

Table 13. Mean (n=4) second-year stem density (# stems/ha) of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	209a*	253a	186a	144a
Canastota	90bc	82b	165ab	102ab
Fish Creek	110bc	144b	208a	95ab
Sherburne	120b	145b	167ab	106ab
SX-61	76c	110b	130b	89b
SX-64	75c	98b	171ab	77b

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

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harvesting the material perhaps more smaller diameter stems would be easier to work with than fewer larger diameter stems.

In terms of differences in willow productivity among the four sites, there were no differences in measured willow biomass two years following coppicing, except for the considerably reduced growth evident in Saskatoon (Figures 29 and 30). Given the relatively similar growing season conditions at each site during the last three years (Table 6), the reduced growth in Saskatoon is probably due to the deleterious impact of the heavy soils at that site on root growth and subsequent water and nutrient uptake. Notwithstanding the successful establishment of these plantations, clearly something was limiting their growth and they are underperforming relative to their genetic yield potentials. Based on data from the State University of New York College of Environmental Science and Forestry, where these clones were developed, these are some of the top producing willows in their breeding program, with expected yields of at least 15 Mg/ha annually with 950 mm precipitation. It is generally believed that in order for these bioenergy production systems to be economically successful, they must produce a minimum of 10 Mg/ha annually. It is obvious, that at this stage, none of the study sites are providing growing conditions conducive to achieving these levels after two years (Figure 30), but given our semi-arid conditions the plantations appear to be growing well, except for the Saskatoon site. Other studies (Sweden, NY) have shown that yield increases of 40% are observed in the second rotation.

As with any production system, willows are also susceptible to damage from wildlife, disease, and insects (Figures 31-34); however, the occurrence of this has been relatively limited after three years. As previously mentioned, the primary concern to date has been weed competition.

4.1.3 Selected Physiological Characteristics of Hybrid Willow

The expectation initially was to quantify some of the important underlying mechanisms which may allow certain clones to outperform others *in situ* within a plantation setting in order to help explain the observed differences in productivity among the clone. However, as reported, no clear trends in productivity appear among the tested clones and perhaps this can explained given the relative similarities in different physiological characteristics among them. Specifically, similar to the growth data, there appears to be no emerging clonal trends in total leaf surface area (Table 14), specific leaf area (Table 15), N and P use efficiency in leaves or stems (Tables 16 and 17), N and P resorption efficiency and proficiency (Tables 18 and 19), cold hardiness (Table 20), or water-use efficiency (Table 21 and Figure 35). Consequently, such comparable physiological characteristics among the

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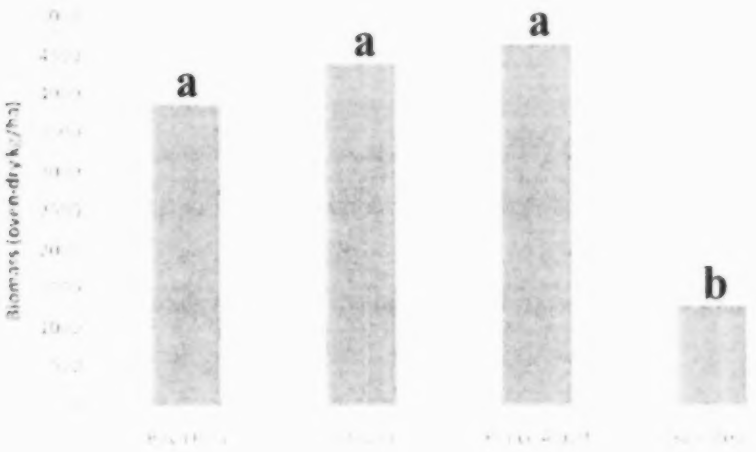

Figure 29. Mean (n=24) productivity of coppiced hybrid willow clones (averaging all clones) at several locations in Saskatchewan after one growing season. For each site, bars with the same letter are not significantly different (P >0.05) using LSD.

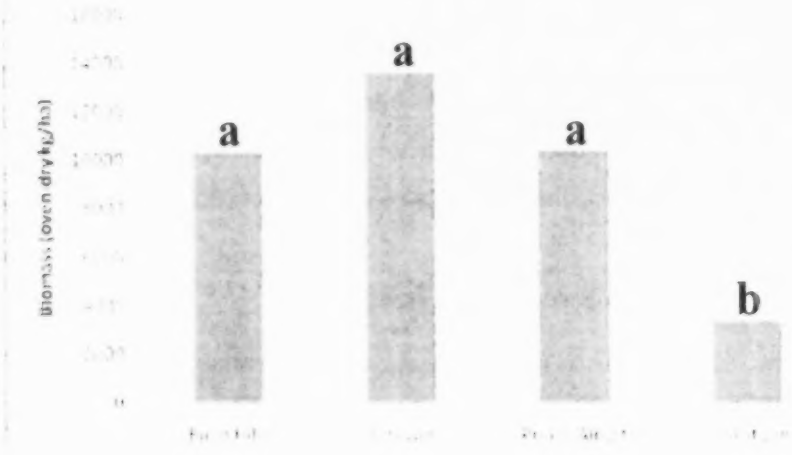

Figure 30. Mean (n=24) productivity of coppiced hybrid willow clones (averaging all clones) at several locations in Saskatchewan after two growing seasons. For each site, bars with the same letter are not significantly different (P >0.05) using LSD.

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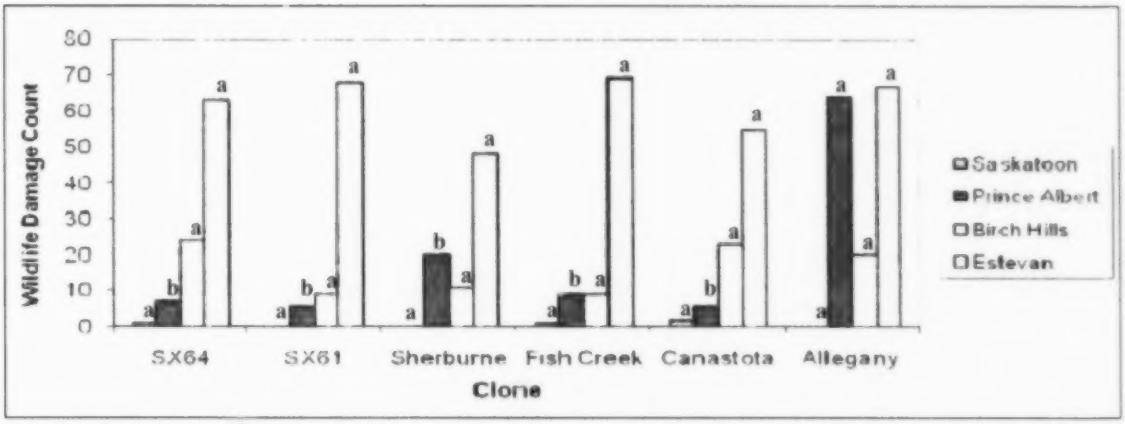

Figure 31. Wildlife damage count for willow clones at all sites during 2007 season. For each site, bars with the same letter are not significantly different (P >0.05) using LSD.

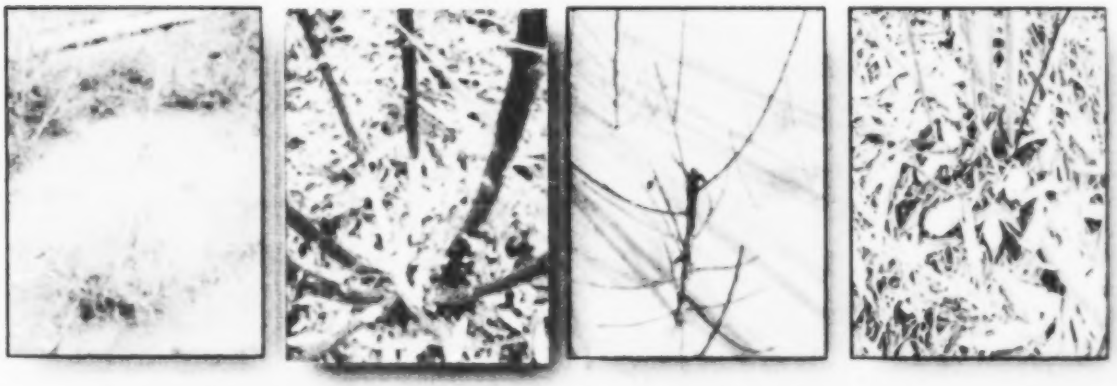

Figure 32. Wildlife damage experienced by hybrid willow clones.

Figure 33. Disease damage experienced by hybrid willow clones.

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Figure 34. Insect damage experienced by hybrid willow clones.

Table 14. Mean (n=4) first-year total leaf surface area (m^2/ha) of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	22.5a*	21.6ab	17.4b	4.7a
Canastota	24.9a	8.8b	34.0ab	5.7a
Fish Creek	9.4b	10.2b	18.9b	2.9a
Sherburne	20.0ab	18.9ab	34.0ab	4.4a
SX-61	14.5ab	27.5a	50.7a	4.4a
SX-64	15.5ab	16.3ab	38.0ab	4.0a

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

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Table 15. Mean (n=4) first-year specific leaf area (cm^2/g) of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	144.1a*	139.6a	159.8a	104.5b
Canastota	147.7a	135.9a	125.4bc	116.6a
Fish Creek	126.9bc	109.0c	141.9ab	113.9ab
Sherburne	136.0ab	121.4abc	126.1bc	114.6a
SX-61	114.8c	116.1bc	125.6bc	108.8ab
SX-64	133.5ab	129.8ab	122.4c	107.4ab

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

Table 16. Mean (n=4) first-year nitrogen (N) and phosphorous (P) use efficiency (g biomass/g nutrient) for leaves of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site							
	Birch Hills		Estevan		Prince Albert		Saskatoon	
Clone	N	P	N	P	N	P	N	P
Allegany	39.6bc	388.7b	39.3d	587.2ab	45.0d	311.0bc	40.1c	606.3bc
Canastota	48.9a	385.5b	47.2a	684.8a	84.3ab	361.6ab	43.4bc	587.3bc
Fish Creek	42.1abc	423.1ab	32.1e	541.9b	46.7cd	236.2c	35.3d	549.8c
Sherburne	37.0c	369.9b	41.9cd	616.0ab	69.8bc	356.2ab	40.2c	625.8b
SX-61	45.4ab	452.9a	43.1bc	611.4ab	67.3bcd	417.4a	50.6a	710.2a
SX-64	48.1a	390.2b	45.7ab	561.3b	102.9a	361.8ab	47.2ab	638.7b

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

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Table 17. Mean (n=4) first-year nitrogen (N) and phosphorous (P) use efficiency (g biomass/g nutrient) for stems of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site							
	Birch Hills		Estevan		Prince Albert		Saskatoon	
Clone	N	P	N	P	N	P	N	P
Allegany	380.2a	1365.9ab	385.3ab	1636.1ab	295.2b	963.6a	190.2a	1012.0bcd
Canastota	428.0a	1374.1ab	302.2b	1369.8b	336.1ab	853.5ab	152.2c	981.7cd
Fish Creek	453.4a	1499.6a	480.5a	1678.6a	332.8ab	898.0ab	192.7a	1082.0a
Sherburne	460.4a	1498.7a	397.0ab	1563.2ab	279.2b	779.5b	180.7ab	1052.0ab
SX-61	463.7a	1532.4a	393.6ab	1663.4a	282.9b	857.9ab	181.5ab	1043.4abc
SX-64	412.7a	1253.2b	290.0b	1517.8ab	454.2a	920.1a	167.2bc	965.2d

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

Table 18. Mean (n=4) first-year nitrogen (N) and phosphorous (P) resorption efficiency (%) for senesced leaves of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site							
	Birch Hills		Estevan		Prince Albert		Saskatoon	
Clone	N	P	N	P	N	P	N	P
Allegany	50.6ab	44.6bc	21.6c	35.8bc	34.1b	31.6a	31.6a	30.6a
Canastota	42.9cd	45.5bc	33.6bc	19.1d	46.7ab	-12.9b	12.9bc	26.3a
Fish Creek	46.1bc	40.0c	51.0a	47.4a	51.5ab	3.9ab	30.3a	26.4a
Sherburne	53.9a	55.4a	20.2c	30.6cd	40.7ab	17.6ab	14.9bc	23.5a
SX-61	48.2abc	46.2b	45.5ab	44.8ab	42.3ab	19.7ab	6.1c	20.1a
SX-64	37.4d	43.6bc	46.1ab	43.7ab	55.9a	4.4ab	18.2b	22.4a

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

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Table 19. Mean (n=4) first-year nitrogen (N) and phosphorous (P) resorption proficiency (g/m^2) for senesced leaves of coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site							
	Birch Hills		Estevan		Prince Albert		Saskatoon	
Clone	N	P	N	P	N	P	N	P
Allegany	0.8ab	0.1bc	1.4a	0.1bc	0.8a	0.1c	1.6b	0.1a
Canastota	0.8b	0.1c	1.0bc	0.1ab	0.5bc	0.2a	1.7b	0.1a
Fish Creek	1.0a	0.1a	1.4a	0.1ab	0.8a	0.3a	1.7b	0.1a
Sherburne	0.9ab	0.1c	1.5a	0.1a	0.7ab	0.2bc	1.9a	0.1a
SX-61	1.0ab	0.1bc	1.1b	0.1c	0.6abc	0.2c	1.7b	0.1a
SX-64	1.0ab	0.1ab	0.9c	0.1c	0.4c	0.2abc	1.6b	0.1a

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

Table 20. Mean (n=4) first-year winter dieback measured among coppiced hybrid willow clones grown at several locations in Saskatchewan. Note: less than 10% of each plantation was affected and these values represent the stem with the worst dieback in each plot.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	30.0b	0.0b	44.0ab	23.0a
Canastota	87.6a	0.7a	27.1ab	32.5a
Fish Creek	49.6b	0.0b	18.4b	34.6a
Sherburne	58.8ab	0.0b	25.3ab	15.3a
SX-61	59.3ab	0.0b	63.3a	27.4a
SX-64	58.7ab	0.0b	22.8b	12.0a

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

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Table 21. Mean (n=4) first-year foliar $\delta^{13}C$ values, used as a surrogate measure of water use efficiency, among coppiced hybrid willow clones grown at several locations in Saskatchewan.

	Site			
Clone	Birch Hills	Estevan	Prince Albert	Saskatoon
Allegany	-26.1a	-27.3a	-27.5a	-25.0a
Canastota	-26.6ab	-28.8c	-28.2ab	-25.0a
Fish Creek	-26.4ab	-27.4a	-27.9ab	-24.8a
Sherburne	-26.1a	-27.4a	-28.0ab	-25.8ab
SX-61	-26.6ab	-27.7ab	-27.9ab	-26.3b
SX-64	-27.1b	-28.2bc	-29.0b	-25.3ab

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

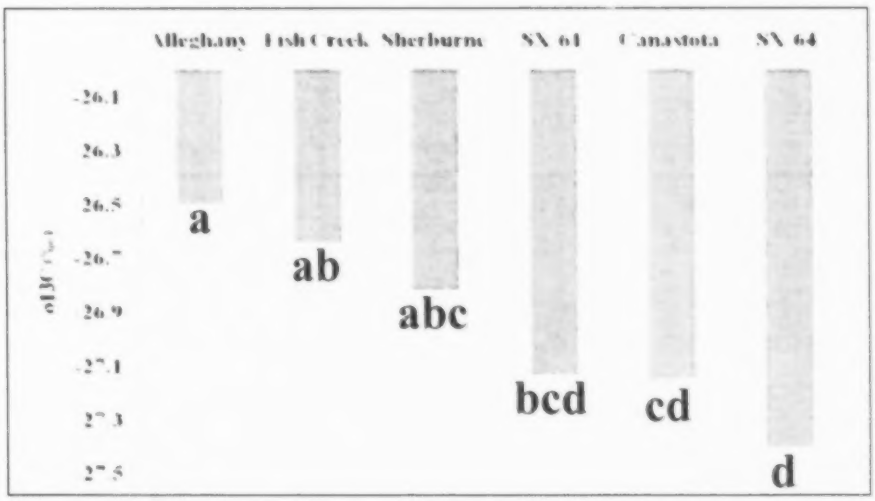

Figure 35. Mean (n=16) first-year post-coppice foliar $\delta^{13}C$ values, used as a surrogate measure of water use efficiency, among hybrid willow clones growing at several locations across Saskatchewan (averaging all sites). Bars with the same letter are not significantly different (P >0.05) using LSD.

willow clones suggest that it may be unreasonable to expect growth differences to occur in the field. It is interesting to note the elevated levels of foliar δ ^{13}C values measured in Saskatoon (Figure 36), which is an effective surrogate measure of water stress, and despite similar growing season conditions, clearly the heavy clay soils at this site exacerbate the available soil moisture required by the willow for optimal growth. Such fine-textured soils are capable of holding more moisture, but evidently, the willow roots cannot access it and this is reflected in the reduced productivity at Saskatoon.

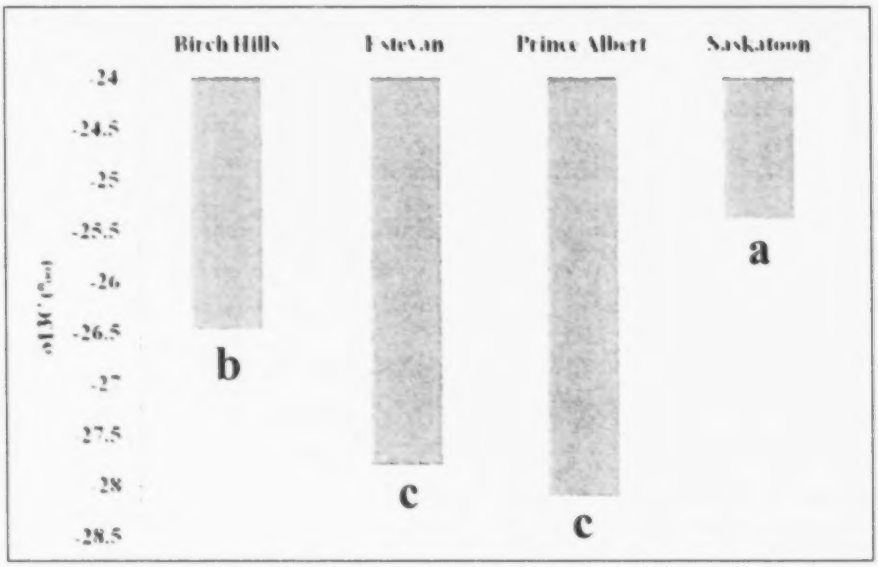

Figure 36. Mean (n=24) first-year post-coppice foliar δ 13C values, used as a surrogate measure of water use efficiency, among hybrid willow clones (averaging all clones) growing at several locations across Saskatchewan. Bars with the same letter are not significantly different (P >0.05) using LSD.

4.1.4 Soil Nutrient Analyses

The results of the conventional soil analyses and the PRS™-probe burials are presented in Tables 22 and 23, respectively. As expected, there was a range in soil chemical properties across the sites and this is advantageous in that it allows for a greater inference space of the study results, in terms of providing useful recommendations, based on the measured growth responses of planted willow at each site. A fundamental question asked regarding SRIC willow plantations is how

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sustainable are these multi-rotation biomass production systems in terms of long-term soil productivity, given the rapid growth rate of willow and large nutrient exports offsite when the biomass

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Table 22. Mean (n=24) soil chemical properties, by depth, measured at several hybrid willow plantations in Saskatchewan.

Site	Depth (cm)	pH	OC	Carbon (%)	Nitrogen	NH_4	NO_3	PO_4	K	Mg	Ca
						μ/g					
Saskatoon	0 - 10	6.41	2.86	2.74	0.32	7.01	13.60	2.54	531.5	1324.9	4095.2
	10 - 20	6.81	2.42	2.36	0.26	6.84	10.35	1.14	345.0	1734.3	4228.4
	20 - 30	7.58	1.80	2.01	0.18	6.08	12.90	0.26	297.3	2501.4	3767.5
	30 - 60	7.49	2.01	2.18	0.27	5.84	16.68	0.85	365.5	2319.7	3744.7
Birch Hills	0 - 10	6.42	4.50	4.31	0.41	9.88	12.29	0.96	534.2	923.7	6111.9
	10 - 20	6.75	3.78	3.61	0.35	9.21	9.47	0.38	332.0	982.2	6032.1
	20 - 30	7.20	2.78	2.71	0.25	8.15	8.09	0.21	252.9	1080.8	5374.3
	30 - 60	7.72	1.57	2.21	0.13	6.70	6.34	0.09	218.2	1534.8	3691.0
Prince Albert	0 - 10	6.24	1.94	1.86	0.14	3.79	5.00	3.53	152.2	240.9	2789.0
	10 - 20	6.18	1.63	1.50	0.11	3.26	7.11	3.07	136.1	222.1	2576.2
	20 - 30	6.74	1.34	1.20	0.09	2.68	6.50	2.12	99.3	203.4	2285.5
	30 - 60	7.32	0.77	0.82	0.04	1.92	5.59	0.80	73.4	173.7	1648.2
Estevan	0 - 10	7.96	2.72	3.17	0.24	5.22	18.97	0.54	476.6	690.3	4732.5
	10 - 20	8.11	1.89	2.81	0.14	4.07	11.62	0.05	255.9	596.8	3826.0
	20 - 30	8.17	1.75	2.82	0.13	4.83	15.91	0.01	186.8	675.5	3945.5
	30 - 60	8.20	1.90	3.09	0.15	5.79	22.03	0.02	238.6	809.9	4529.8

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Table 23. Mean (n=4) cumulative nutrient supply rates, measured using *in situ* burials of PRS™-probes, from early May to late August, 2007 at several hybrid willow plantations in Saskatchewan.

	NH_4^+	NO_3^-	Total N	P	K	S	Ca	Mg	Cu	Zn	Mn	Al	Fe	B
Site	μg/10cm^2/12 weeks													
Birch Hills	2.8ab	1828.7a	1831.5a	7.6b	170.0b	541.5a	4873.5b	700.0b	2.2b	5.5a	20.9a	88.1a	231.9a	3.7b
Estevan	2.0b	1531.8a	1533.8a	6.3b	136.1b	168.3b	5553.8a	607.2c	1.7b	1.7b	2.2b	89.6a	12.5b	3.8b
Prince Albert	2.2b	679.2b	681.3b	96.6a	284.9a	96.7b	4285.0bc	489.2d	0.2c	2.6b	3.9b	94.5a	43.2b	4.6a
Saskatoon	3.6a	1553.5a	1557.1a	8.7b	87.1c	111.8b	3939.5c	968.8a	3.6a	3.1b	5.4b	93.7a	51.9b	3.1b

* Means within a column followed by the same letter are not significantly different (P >0.05) using LSD.

is harvested. Exacerbating the issue is the probable reality that farmers will not take their best land out of annual crop production for these SRIC plantations, instead more than likely relegating them to any available marginal land to manage their risk. For instance, Steckler (2007) found that depending on the nutrient, marginal soils (i.e., Agricultural Capability Classification 4 and 5) in Saskatchewan supporting SRIC hybrid poplar plantations (with biomass production ranging from 6.3-7.5 Mg ha^{-1} yr^{-1}), would require from six to fifty years to rebound from the exported nutrients in harvested biomass, through natural inputs from mineral weathering and atmospheric deposition. Relative to hybrid poplar, hybrid willow has considerably greater biomass production (i.e., up to 22 Mg ha^{-1} yr^{-1}; Larsson, 2001). Moreover, the expected lifespan of a willow plantation is at least seven rotations (Heller et al., 2003) and due to changes in above- and below-ground growth allocation patterns in later rotations as subsequently more biomass is allocated above-ground once the root system is established (Volk et al., 2004b), incremental growth gains up to 130% larger can be expected until the fourth rotation (Larsson, 2001). Consequently, in order to support sustainable soil management practices, the need for developing accurate nutrient budgets for these SRIC willow plantations is readily apparent and having such detailed soils information will play an important role in achieving his goal.

4.1.5 Non-destructive Techniques for Estimating Above-ground Willow Biomass

Two non-destructive techniques for estimating above-ground willow biomass were developed and are showing promising results. Firstly, conventional allometric equations were successfully produced for all six clones at each of the four study sites (Table 24). Using these models relating stem diameter and leafless dry stem weight, individuals growing these same clones will be able to come up with reliable biomass estimates with which to base their subsequent management decisions. Secondly, the LAI-2000 Plant Canopy Analyzer was used to measure light attenuation through different willow canopies, to yield a Stem Area Index, with which to relate to harvested willow biomass. Given the strong correlations ($r^2 > 0.97$; $p < 0.05$; Figure 37) between the harvested willow biomass and measured Stool Area Index, regardless of willow growth form (i.e., single stem Charlie or multi-stem SV1), the use of the LAI-2000 appears to be a promising non-destructive and elegant mensurative technique for providing reliable estimates of above-ground biomass, especially with adequate weed control within the plantation. On sites where there is an abundance of understory species, the unit had difficulties separating the crop/non-crop species, which can affect its accuracy (Figure 38). Despite this apparent shortcoming, correlations between the harvested willow biomass and measured Stool Area Index

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Table 24. Allometric relationships between stem diameter (measured at 30 cm above-ground) and leafless dry stem weight different willow clones grown at several hybrid willow plantations in Saskatchewan.

		Year 1		Year 2	
Site	Clone	Power Equation	R^{2}*	Power Equation	R^{2}*
Birch Hills	Alleghany	$y = 0.1521x^{2.5068}$	0.9927	$y = 0.0647x^{2.8044}$	0.9742
	Canastota	$y = 0.1109x^{2.6032}$	0.9923	$y = 0.1141x^{2.5581}$	0.9925
	Fish Creek	$y = 0.1919x^{2.4478}$	0.9954	$y = 0.1391x^{2.5556}$	0.9946
	Sherburne	$y = 0.1548x^{2.4609}$	0.9918	$y = 0.1551x^{2.4841}$	0.9944
	SX-61	$y = 0.1643x^{2.4319}$	0.9957	$y = 0.1091x^{2.5731}$	0.9963
	SX-64	$y = 0.1379x^{2.5568}$	0.9952	$y = 0.1208x^{2.5934}$	0.9909
Estevan	Alleghany	$y = 0.1557x^{2.4956}$	0.9702	$y = 0.0846x^{2.7076}$	0.9911
	Canastota	$y = 0.1291x^{2.5359}$	0.9858	$y = 0.0784x^{2.6939}$	0.9885
	Fish Creek	$y = 0.1781x^{2.4538}$	0.9911	$y = 0.0823x^{2.755}$	0.9896
	Sherburne	$y = 0.1903x^{2.3612}$	0.9891	$y = 0.1048x^{2.6153}$	0.9928
	SX-61	$y = 0.1797x^{2.3927}$	0.9962	$y = 0.0772x^{2.6999}$	0.9902
	SX-64	$y = 0.1742x^{2.4435}$	0.9906	$y = 0.1135x^{2.5961}$	0.9941
Prince Albert	Alleghany	$y = 0.1205x^{2.5802}$	0.9891	$y = 0.0837x^{2.686}$	0.9811
	Canastota	$y = 0.0382x^{2.9415}$	0.9882	$y = 0.0791x^{2.6849}$	0.9919
	Fish Creek	$y = 0.0743x^{2.7855}$	0.9892	$y = 0.0993x^{2.6821}$	0.9941
	Sherburne	$y = 0.0645x^{2.7705}$	0.9904	$y = 0.0453x^{2.8797}$	0.9685
	SX-61	$y = 0.0369x^{2.9508}$	0.9872	$y = 0.0705x^{2.6966}$	0.9953
	SX-64	$y = 0.0699x^{2.7893}$	0.9837	$y = 0.0978x^{2.6778}$	0.9951
Saskatoon	Alleghany	$y = 0.2521x^{2.2038}$	0.9571	$y = 0.098x^{2.5833}$	0.9931
	Canastota	$y = 0.1645x^{2.3445}$	0.9793	$y = 0.0855x^{2.5959}$	0.9946
	Fish Creek	$y = 0.2279x^{2.2646}$	0.9926	$y = 0.0911x^{2.6493}$	0.9894
	Sherburne	$y = 0.2218x^{2.2557}$	0.9943	$y = 0.0904x^{2.6398}$	0.9986
	SX-61	$y = 0.2311x^{2.1919}$	0.9888	$y = 0.1297x^{2.4608}$	0.9883
	SX-64	$y = 0.21x^{2.2868}$	0.9881	$y = 0.0846x^{2.6723}$	0.9891

* $P < 0.05$

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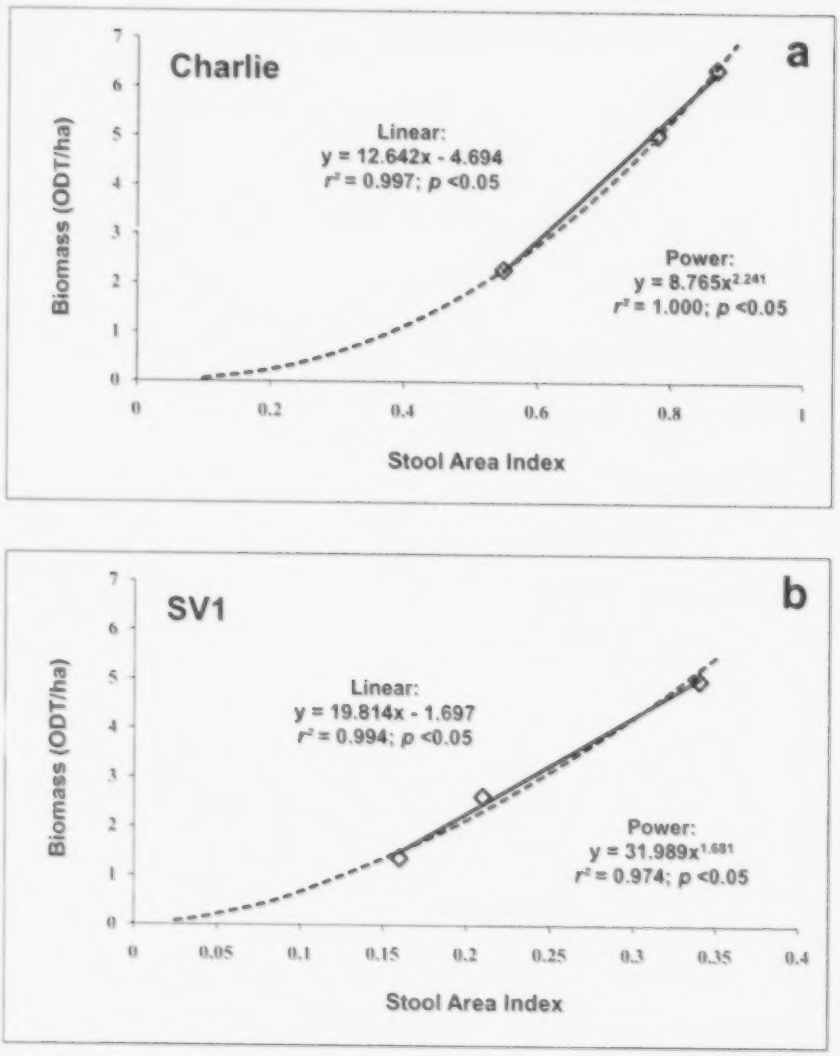

Figure 37. Relationship between harvested bed biomass of different non-coppiced two-year-old willow clones and Stool Area Index, measured using a LAI-2000 Plant Canopy Analyzer, with either a (a) linear or (b) non-linear power regression model. Charlie has a single stemmed growth form contrasted by the multi-stemmed SV1.

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Figure 38. Comparison between gap-fraction perspective as seen with (a) and without (b) adequate control of understory weeds.

remained relatively strong ($r^2 > 0.65$; $p < 0.05$; Figure 39). Having said this, on these weedy sites, subsequent rotations having an established root system, will achieve canopy closure much quicker, thereby effectively controlling non-crop understory vegetation and undoubtedly improve the reliability of this method on these types of sites.

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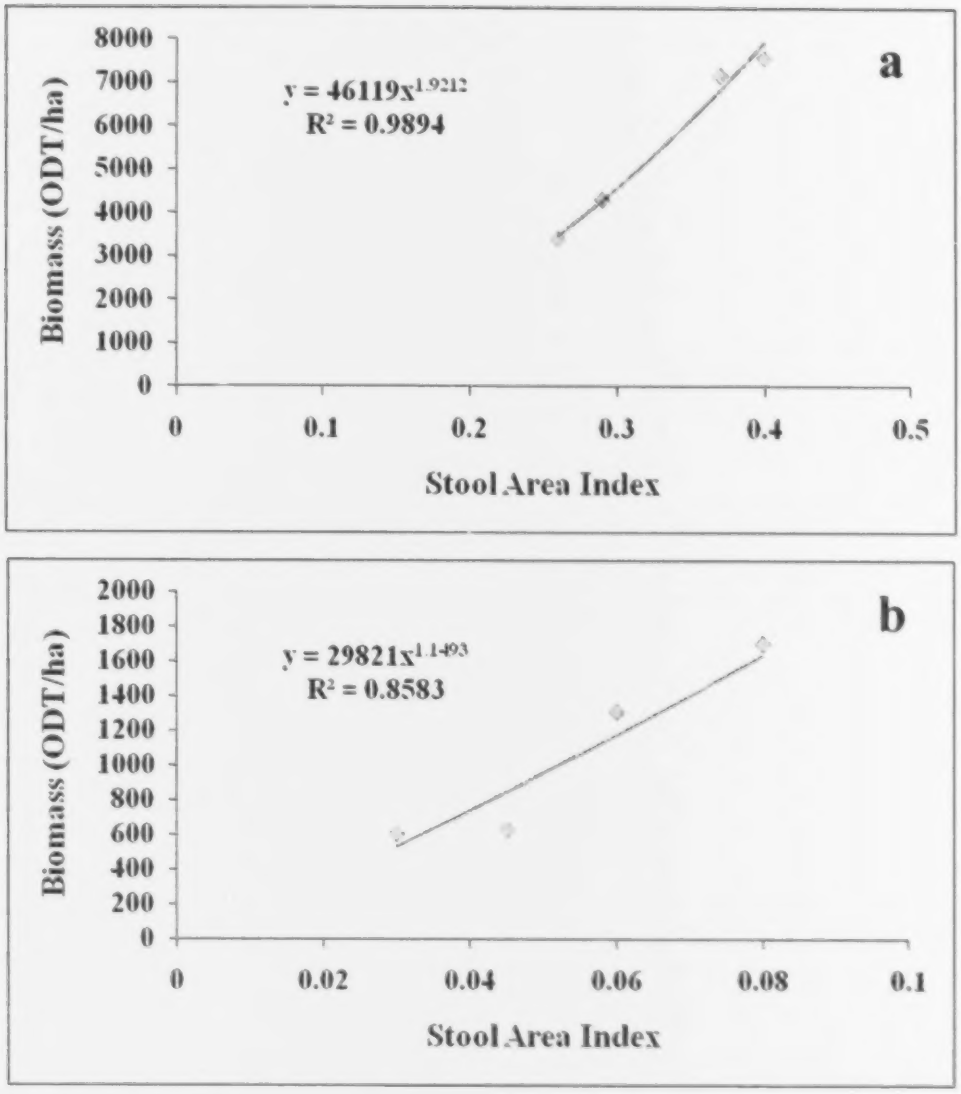

Figure 39. Relationship between estimated biomass of one-year-old willow clone SX-61 and Stool Area Index, measured using a LAI-2000 Plant Canopy Analyzer, at two different plantations having either superior weed control (a; Estevan) or poor weed control (b; Saskatoon)

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4.2 Nitrogen Fertilization Trial

Shoot biomass is the financially profitable product derived from willow biomass plantations. Two years after planting, with coppicing taking place one year after planting, the shoot biomass ranged from 27.6 - 138.7 g. In the current N fertilization trial, shoot biomass was not found to be influenced by the applied fertilization treatments, the clones used, by site specific soil properties (extractable NO_3^-, NH_4^+ and PO_4^- concentrations, pH, electrical conductivity, organic carbon or total carbon) or by other measureable plant characteristics (number of shoots per plant, height and diameter of the tallest shoot per tree and total N and P). This demonstrates that there was no difference under the two fertilization treatments.

Browsing by deer (*Odocileus virginianus*) occurred at the end of the 2008 growing season and frequently throughout the 2009 growing season not allowing trees to reach their full potential. Without the presence of the lingering deer population, it is anticipated that better production would be observed and that a few influential variables may have been made apparent and some fertilization effect may have surfaced.

4.2.1 Plant Nutrient Analysis

Total N and P of foliar samples were found to vary from year to year (Figure 40). In 2008 the total N and P ranged between 31.5 – 48.9 mg g^{-1} and 13.6 – 23.7 mg g^{-1}, respectively. Total N was not significantly affected by any of the applied or measured factors. Foliar N did not differ between fertilization treatments but did differ significantly between Saratoga and India as well as Tully Champion and Saratoga. Total foliar P did was not influenced by the applied or measured factors and did not vary significantly between clones. It did, however, vary significantly between the fertilization treatments.

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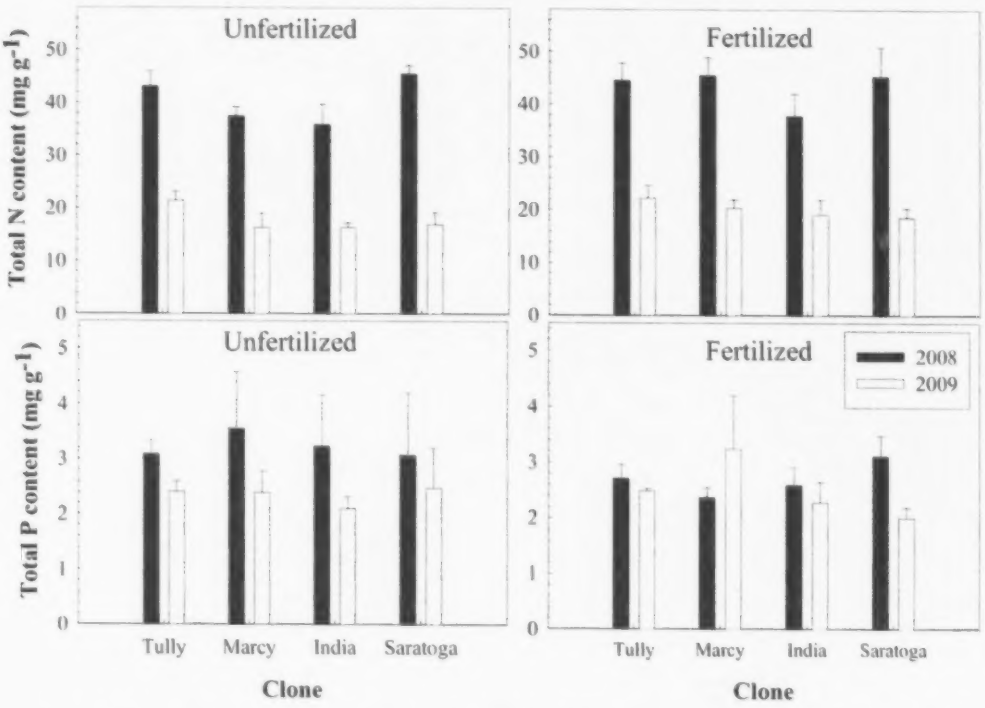

Figure 40. Total N and P contents for foliar samples taken from willow trees in Prince Albert affected by fertilized (100 kg N ha^{-1}) and unfertilized treatments.

In 2009, the foliar nutrient concentrations decreased to 2.16 – 4.37 mg g^{-1} for total N and 1.86 – 4.11 mg g^{-1} for total P. Total foliar N was strongly affected by clone in the second growing season. Total foliar P was significantly controlled by clone preliminary PO_4^- levels, the height of the tallest shoot and the diameter of the tallest shoot at 30 cm about the soil surface.

4.2.2 Soil Nutrient Analysis

Soil extractable nutrient concentrations (NO_3^-, NH_4^+ and PO_4^-) were monitored throughout the study and were found to fluctuate depending on the sampling date. Fertilization application only had significant effects on the concentrations of some nutrients at certain sampling times; NO_3^-, NH_4^+ and PO_4^- in the top 10 cm of soil one week after fertilization, NO_3^- in the top 20 cm and NH_4^+ in the top 10 cm of the soil at the end of 2008 and NO_3^- in the top 10 cm of soil at the end of the 2009 growing season. Soil nutrient contents, whether initial or post fertilization, did not have significant effects on shoot biomass production.

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4.2.3 ^{15}N Labeling Trial

The ^{15}N labelled fertilizer was applied to quantify the ability of willows to take up and utilize N fertilizers. Nitrogen recovery of each clone and each plant part was calculated using the characteristics measured by the isotopic ratio mass spectrometer (total N in the samples in % and grams and atom $\%^{15}N$ abundance which is the amount of ^{15}N in the sample). The values are presented in (Figure 41).

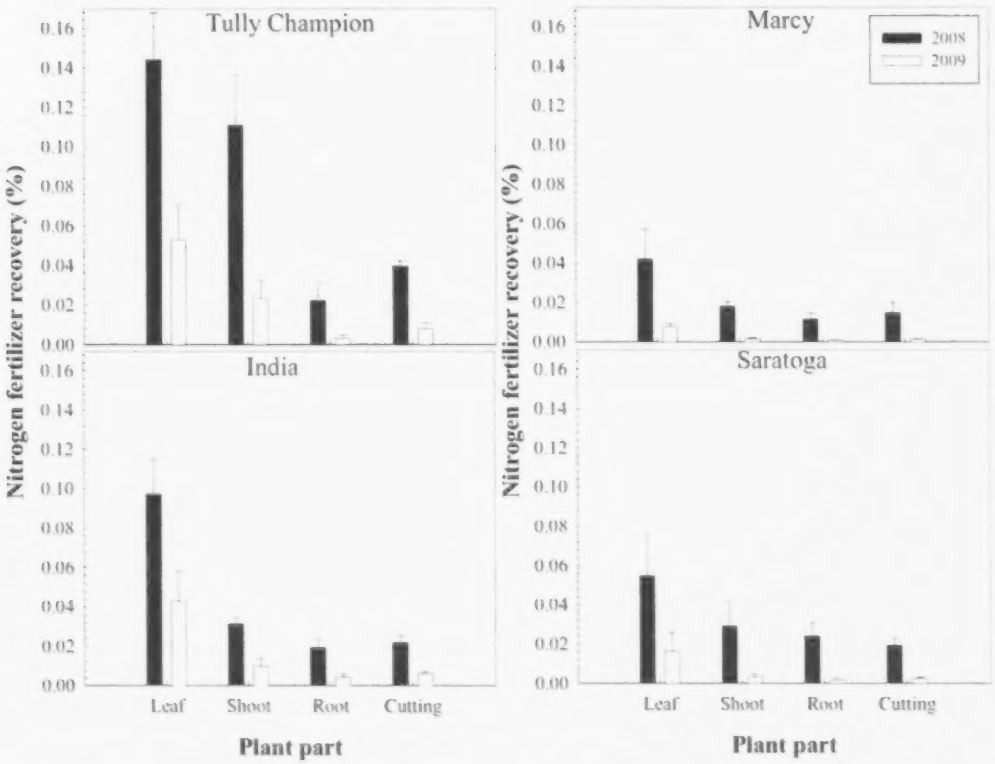

Figure 41. Nitrogen fertilizer recovery of four willow clones at the Prince Albert research site measured using the application of ^{15}N stable isotope.

In 2008, N recovery was found to be significantly controlled by the experimental treatments of clone and plant. It is palpable that factors used in the calculation of a value should have an effect on the outcome of the new term. The only significant differences between clones were noted between Tully Champion and Marcy. Leaves were found to be better capable of recovering soil N than roots and cuttings but the other plant parts did not differ between each other.

In 2009, a similar story was shown. Nitrogen recovery by willows was observed to be significantly affected by clone and plant part. Significant deviations in clones were evident between

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Marcy and India, Tully Champion and Marcy as well as Tully Champion and Saratoga. Nitrogen recovery was significantly greater for leaves than the three other plant parts. It is plausible that the perceived clonal discrepancies resulted from the genetic makeup and thus the ability of each clone to utilize the available nutrients.

The N recovery by willows quantified in this study was very small. Total N recovery for the entire plant ranged from 0.3165 – 0.0855 % for Tully Champion and Marcy, respectively with India and Saratoga lying within that range. When taking into account the cost of fertilizer and its application, it appears on very sandy soils that < 1 % will actually be recovered and utilized by the plant.

In both 2008 and 2009 the amount of label in the soil in the immediate area surrounding the labelled trees was only slightly higher than the natural abundance levels of ^{15}N suggesting that the label had been leached though the soil profile beyond the reach of the plants' young root systems perhaps leading to the minute N recovery values.

4.3 Growth Chamber Fertilization Trial

4.3.1 Growth Curves

The progress of tree height growth was surveyed throughout the entire experiment to achieve a general overview of willow growth trends under optimal growing conditions. On both Saskatoon and Prince Albert derived soils (Figure 42), most trees became infected with disease on approximately day 60. Tree heights had increased exponentially until this point and then after day 60 tree heights decreased. On the Saskatoon soil, only the control treatment for Tully Champion was able to reach and exceed the height the trees were before infection set in. On the Prince Albert soil, most clones under most treatments were able to surpass the height at time of infection.

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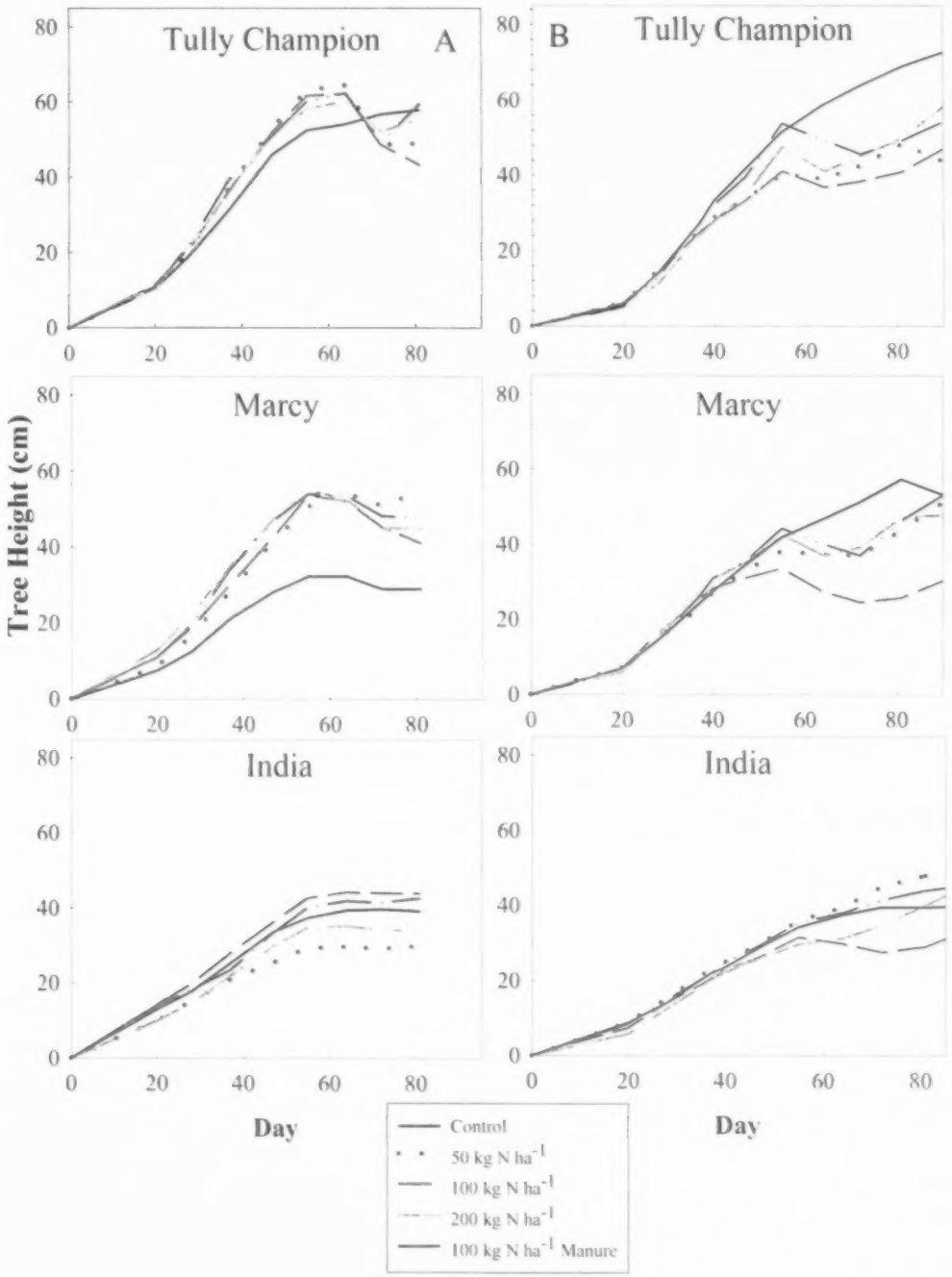

Figure 42. Growth curves of trees grown on Saskatoon (A) and Prince Albert (B) derived soil in an indoor growth chamber fertilization trial.

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4.3.2 Shoot Biomass

Under optimal growth conditions supplied by an indoor controlled environment chamber, it was revealed that shoot biomass was significantly influenced by the soils, clones, fertilization treatments, foliar N and P, as well as leaf and root biomass collected at the time of tree harvesting. Initial cutting diameter, disease infection, re-growth from diseased shoots and the number of shoots and concentrations of extractable NO_3^-, NH_4^+ and PO_4^- at the time of tree harvest had no effects on the shoot biomass produced.

Shoot biomass ranged from 0 – 3.59 g and 0 – 5.34 g per plant on Saskatoon and Prince Albert derived soils, respectively. These values were significantly different. Encompassing both soil types, significant differences in shoot biomass were only noted between Marcy and India clones. There were, however, no statistical differences in shoot biomass between treatments, disease affected trees or those that re-sprouted after infection.

The number of shoots per tree was significantly different between soils however not between clones and treatments (Tables 25 and 26). Significant differences of the height of the tallest shoot per tree was observed between soils and clones (only between Tully Champion and India) and not between treatments. The number of shoots and the height of the tallest shoot per tree did not have any influence on shoot biomass production which is supported by the fact that few significant differences were noted between experimental treatments, such as clone and fertilization rates. Leaf biomass was significantly different between soils and all clones but not fertilizer treatments. Root biomass was significantly different between soils but not between clones or treatments. Leaf and root biomasses affected the shoot biomass production. It is probable that leaf biomass offered a greater photosynthetic surface area and that root biomass assisted the plant with taping into the available soil nutrient reserves before they were lost from the system. The harvest data shows that when choosing clones, it is important to select ones with a large leaves in order to obtain a greater shoot yield. It appears that fertilization treatments had no effect on these two variables so clonal selection should be of utmost importance.

4.3.3 Soil Nutrient Analysis

Extractable soil NO_3^-, NH_4^+ and PO_4^- concentrations were measured at the end of the study. Soil NO_3^- and PO_4^- differed significantly between soils while NH_4^+ did not. Soil NO_3^- and PO_4^- was not significantly different between clones while Tully Champion and Marcy both differed from India

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Table 25. Measurements taken of trees harvested from Saskatoon soil at day 90 of the indoor growth chamber study.

Clone	Treatment	Diameter†	Shoots‡	Height§	Biomass		
					Leaf	Shoot	Root
		(mm)	*(#)*	*(cm)*	*(oven dried g per tree)*		
Tully	0	7.27	2.75	54.5	2.31	2.20	0.888
Champion	50	7.10	2.25	45.3	2.08	2.80	0.735
	100	7.39	2.00	42.0	2.58	2.46	0.863
	200	6.97	2.25	47.3	2.62	2.86	0.968
	Manure	6.84	2.00	61.0	2.86	3.21	0.958
Marcy	0	5.71	2.00	28.8	1.20	1.55	0.520
	50	6.69	1.50	56.3	1.42	2.08	0.513
	100	7.90	2.25	36.5	1.61	2.42	0.758
	200	8.44	2.00	38.8	2.18	2.75	0.885
	Manure	6.99	2.25	41.5	1.98	2.69	0.895
India	0	8.96	1.75	40.0	2.96	2.53	0.788
	50	8.02	2.25	29.3	2.15	1.99	0.628
	100	8.84	1.75	43.8	2.46	2.67	0.823
	200	7.67	2.00	33.3	2.43	2.27	0.873
	Manure	9.43	2.25	44.5	2.84	2.97	1.19

† Cutting diameter at soil surface measured on day of planting.

‡ Number of shoots per tree.

§ Height of the tallest shoot per tree.

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Table 26. Measurements taken of trees harvested from Prince Albert soil at day 90 of the indoor growth chamber study.

Clone	Treatment	Diameter†	Shoots‡	Height§	Biomass		
					Leaf	Shoot	Root
		(mm)	*(#)*	*(cm)*	*(oven dried g per tree)*		
Tully	0	5.86	2.25	72.5	2.46	2.25	4.34
Champion	50	7.53	3.25	43.7	2.62	3.15	3.16
	100	7.64	3.50	46.8	2.91	3.22	3.77
	200	6.71	2.50	58.0	3.28	3.46	6.81
	Manure	5.68	2.25	54.0	2.90	3.15	3.94
Marcy	0	8.64	2.50	53.3	2.04	2.59	3.13
	50	6.32	2.25	51.0	2.17	2.54	4.04
	100	6.76	3.00	30.3	1.93	2.42	2.59
	200	8.64	2.25	47.8	3.29	3.99	3.03
	Manure	6.94	2.25	53.0	2.79	3.16	2.49
India	0	8.71	2.75	39.8	3.11	3.09	5.16
	50	7.87	2.25	48.0	4.95	4.27	4.45
	100	9.80	3.50	33.8	3.82	3.91	4.53
	200	9.12	2.75	45.8	5.05	4.06	3.91
	Manure	7.83	2.50	45.5	4.65	3.79	5.36

† Cutting diameter at soil surface measured on day of planting.

‡ Number of shoots per tree.

§ Height of the tallest shoot per tree.

for soil NH_4^+ concentration (Figure 43). This may be explained by the similar genetic makeup of Marcy and Tully Champion which were both *Salix miyabeana* crossed with another *Salix* parent (Table 3). Soil NO_3^- and NH_4^+ were not found to differ between fertilizer treatments but it was noted that the only significant differences in PO_4^- was between the manure treatment and 100 kg granular N ha^{-1}. The

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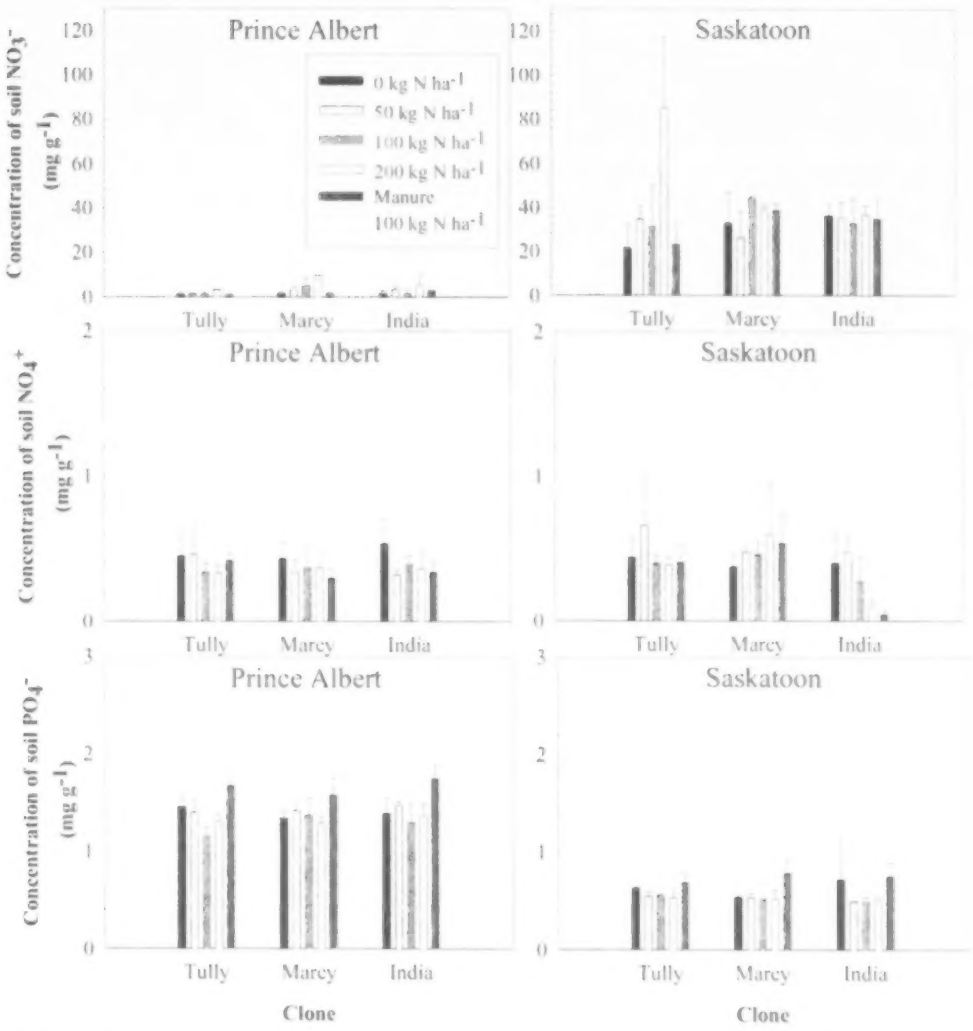

Figure 43. Final soil extractable nutrients for both Prince Albert and Saskatoon derived soils used in indoor growth chamber N fertilizer experiment.

high concentration of PO_4^- in the manure (2.51 mg g^{-1}) is a plausible reason that the PO_4^- concentration in the soil was that much higher under manure treatment than the same N application in a single nutrient granular N fertilizer.

4.3.4 Plant Nutrient Analysis

Both foliar total N and P concentrations were significantly different between the Saskatoon and Prince Albert sites (Figures 44 and 45) reflecting the different soil nutrient contents of the two soils.

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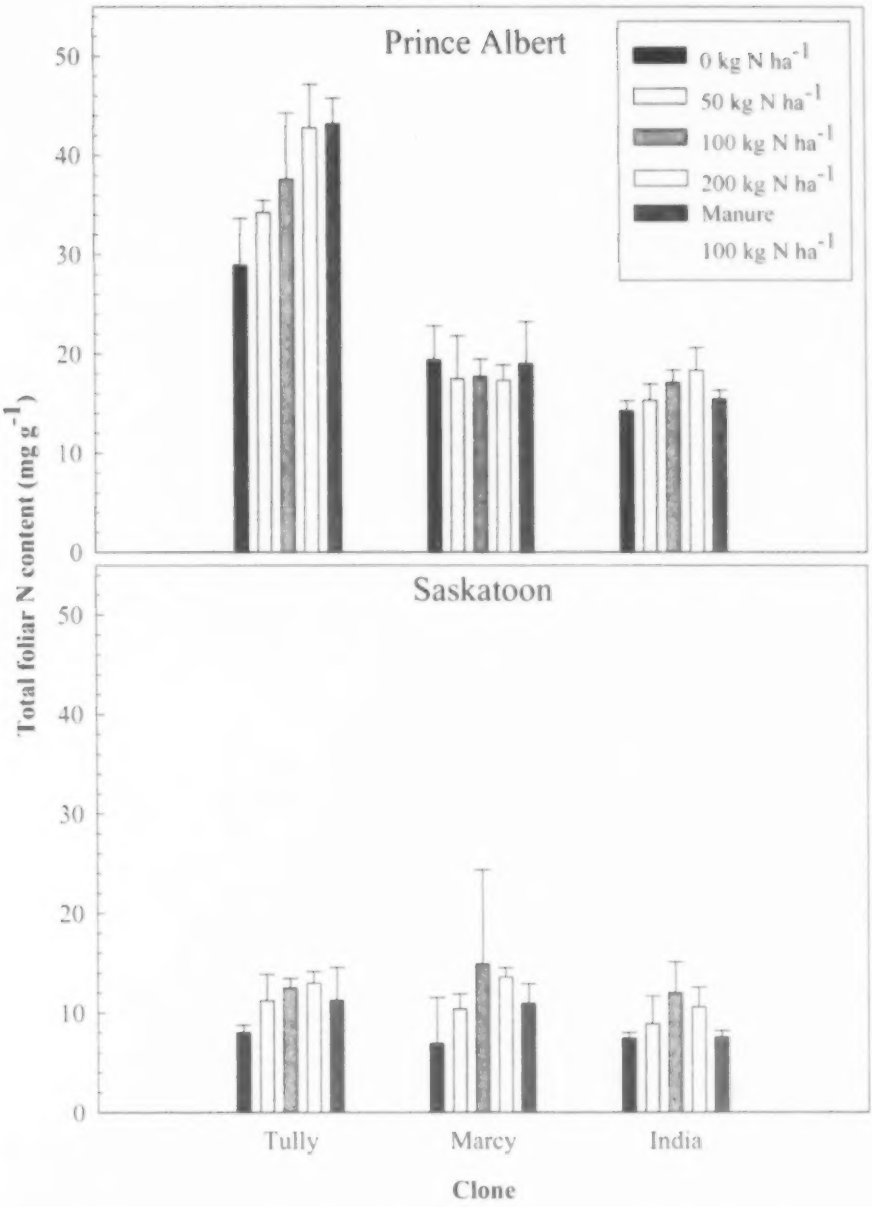

Figure 44. Total foliar N content for willow clones over a range of N fertilization treatments on two soils carried out in an indoor growth chamber.

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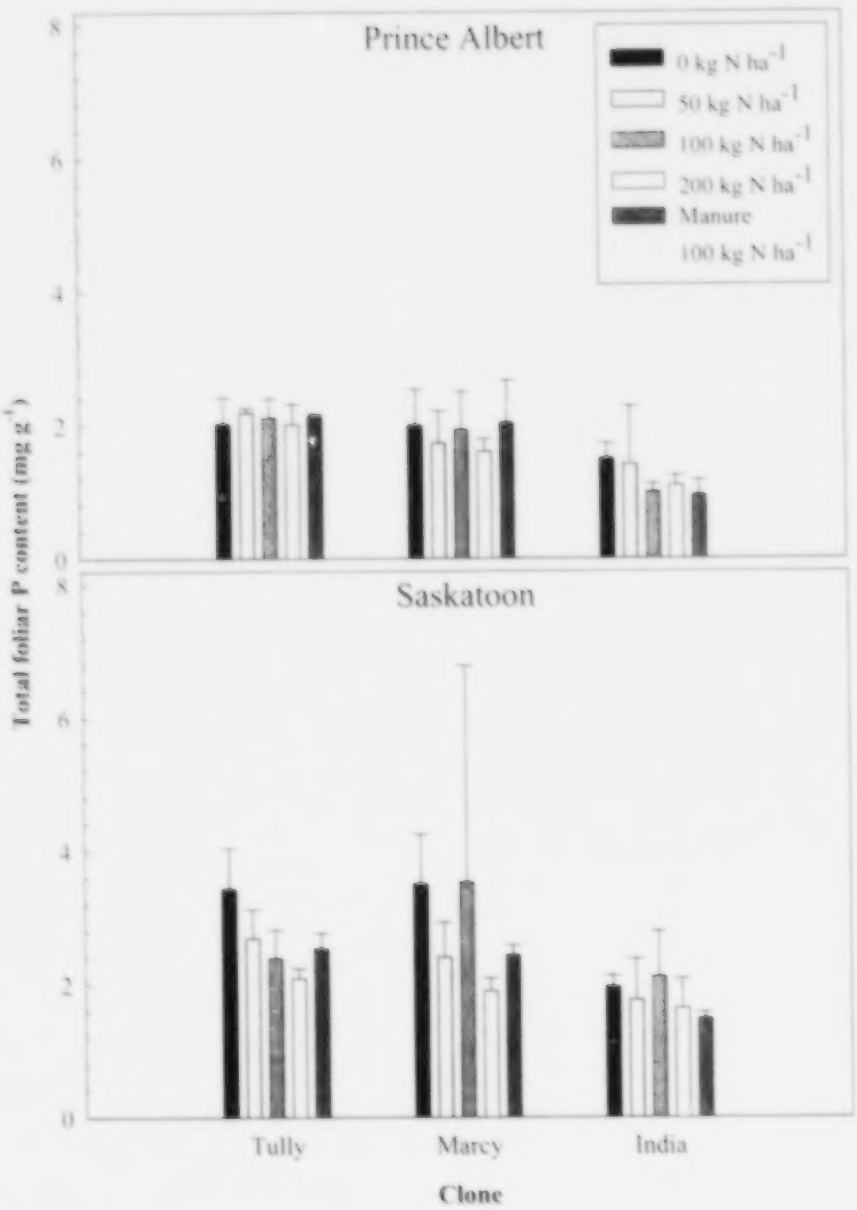

Figure 45. Total foliar P content for willow clones over a range of N fertilization treatments on two soils carried out in an indoor growth chamber.

Total N showed differences between India and the two other clones while total P showed contrasts between Tully Champion and the other two clones. There were differences between the treatments of 200 kg N ha^{-1} and the control for total N but no discrepancies were present for total P. It is reasonable to think that because of their genetic similarities, Tully Champion and Marcy are more efficient at N

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uptake while Tully Champion is more efficient at P uptake maybe due to the *S. viminalis* in its genetic makeup.

4.4 Fertilization and Irrigation Trial

For both willow clones, after two years there was a highly significant (*P values* < 0.0001) growth response to irrigation in both growing seasons, with no significant (*P values* > 0.05) effect of fertilization, except for the 2x recommended rate applied to the clone SV1 (Figures 46 and 47). The positive willow growth response to added water is indicative of the fact that within the semi-arid climate of Saskatchewan, moisture availability often is considered the primary controller limiting growth for both annual and perennial plant species (Akinremia et al., 1996; Hogg and Schwarz, 1997). These results indicate that if a suitable (i.e., high yielding) willow is grown on fertile soil, irrigation alone should be enough to achieve the critical productivity level of 10 Mg/ha to support the economic viability of the operation.

The lack of measured growth response to added fertilizer after two years for either clone, probably is attributable to the relatively fertile Class 2-3 Sutherland Association soils at the site. Having said this, there was a significant growth response for SV1 at the 2x recommended rate, which is intriguing and may be explained by the low fertilizer use efficiency of broadcasted fertilizer within these agroforestry systems often reported in the literature. Additionally, recent research using ^{15}N-labelled fertilizer with hybrid poplar and willow has reported crop use efficiency of broadcasted fertilizer N to be less than five percent, which is staggering compared with the commonly accepted value of 50 % with agronomic crops. This may help to explain the lack of willow growth responses to fertilization after two years in this study and the other fertilizer study, although each year there was hand weeding of non-crop vegetation for most of the growing season and leaching is essentially non-existent at this heavy clay site, so at this point it is unclear why the trees do not utilize more of the applied nutrients. It is important to keep in mind though that an important component of sustainable stewardship practices is to replenish what has been removed. Specifically, although there essentially has been no measured effect of added fertilizer after two years, the recommended rate is intended to not only match willow growth requirements, but also replenish nutrients exported when harvesting the willow. Using this type of balanced nutrient management, either using inorganic or organic nutrient amendments, will help support the long-term site productivity of any site. Also, it was encouraging to observe no negative effect of these treatments on the cold hardiness of these clones (Figure 48).

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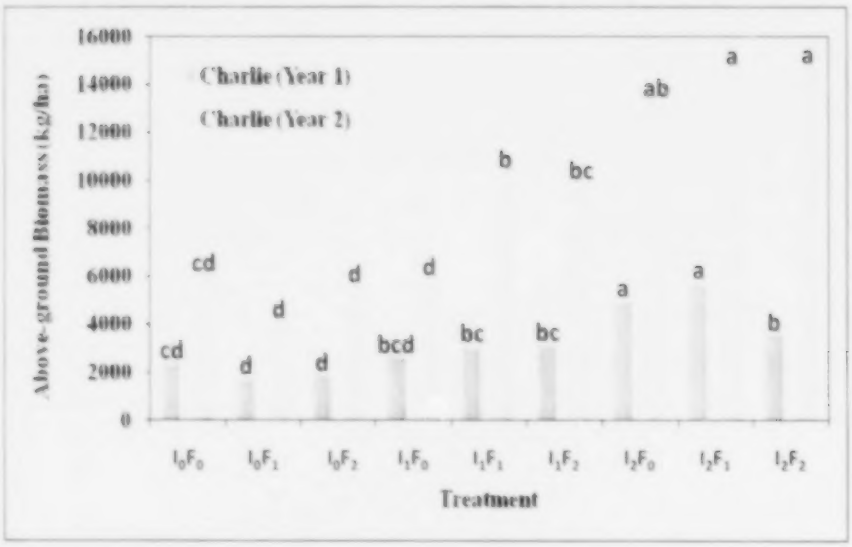

Figure 46. Mean (n=3) effect of irrigation and fertilization on above-ground biomass production of the hybrid willow clone Charlie after two growing seasons. The three irrigation treatments consist of either no additional water added above rainfall (I0) or drip irrigation used to maintain the available soil moisture at either deficit (I1) or full (I2) levels. The three fertilization treatments include no fertilizer (F0) or fertilizer applied once annually at either the recommended rate (F1; 100:30:80:20 kg/ha N:P:K:S) or 2x the recommended rate (F2). For each year, bars having the same letter are not significantly different (P >0.05) using LSD.

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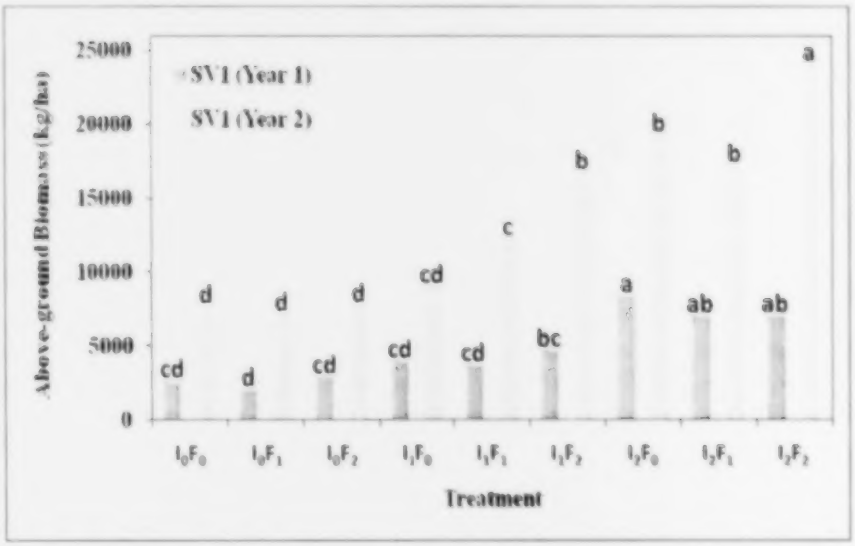

Figure 47. Mean (n=3) effect of irrigation and fertilization on above-ground biomass production of the hybrid willow clone SV1 after two growing seasons. The three irrigation treatments consist of either no additional water added above rainfall (I0) or drip irrigation used to maintain the available soil moisture at either deficit (I1) or full (I2) levels. The three fertilization treatments include no fertilizer (F0) or fertilizer applied once annually at either the recommended rate (F1; 100:30:80:20 kg/ha N:P:K:S) or 2x the recommended rate (F2). For each year, bars having the same letter are not significantly different (P >0.05) using LSD.

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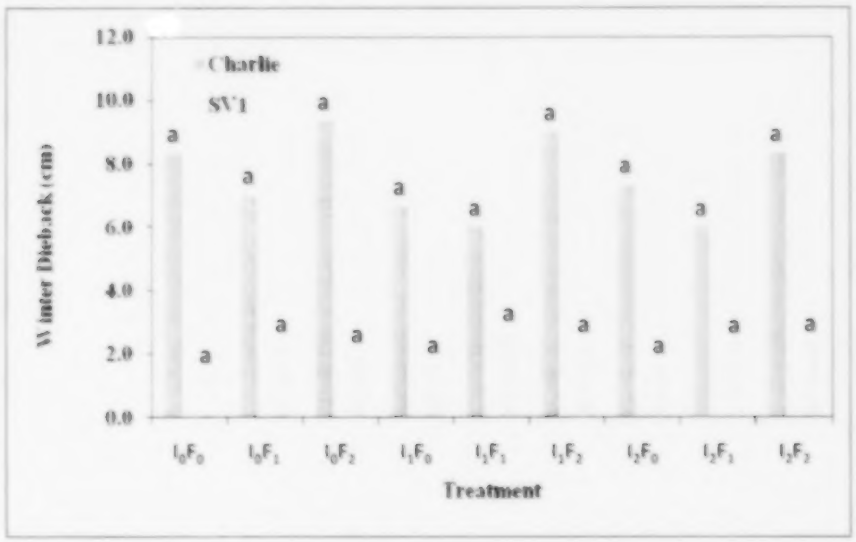

Figure 48. Mean (n=3) first-year winter dieback measured among coppiced willow clones. The three irrigation treatments consist of either no additional water added above rainfall (I0) or drip irrigation used to maintain the available soil moisture at either deficit (I1) or full (I2) levels. The three fertilization treatments include no fertilizer (F0) or fertilizer applied once annually at either the recommended rate (F1; 100:30:80:20 kg/ha N:P:K:S) or 2x the recommended rate (F2). For each clone, bars having the same letter are not significantly different (P >0.05) using LSD.

4.5 Salinity Tolerance of Hybrid Willow

Most willow clones tested in this study were able to tolerate slightly saline conditions (≤ 5.0 dS/m), with no effect of salt level on number of stems, height, or total above- and below-ground biomass (Figures 49-52). In addition, several clones (Alpha, India, Owasco, Tully Champion, and 01X-268-015) showed no reduction in growth with moderately salinity (≤ 8.0 dS/m; Figure 52). When comparing the growth of relatively salt tolerant and salt intolerant willow, it is interesting to note the more lush willow growing in the soils with greater salinity (Figure 53). This was probably due to the presence of residual fertilizer present in these soils given the historically poor crop growth in these saline landscape positions despite annual fertilizer inputs, which would limit plant uptake and result in higher soil test levels (Table 27).

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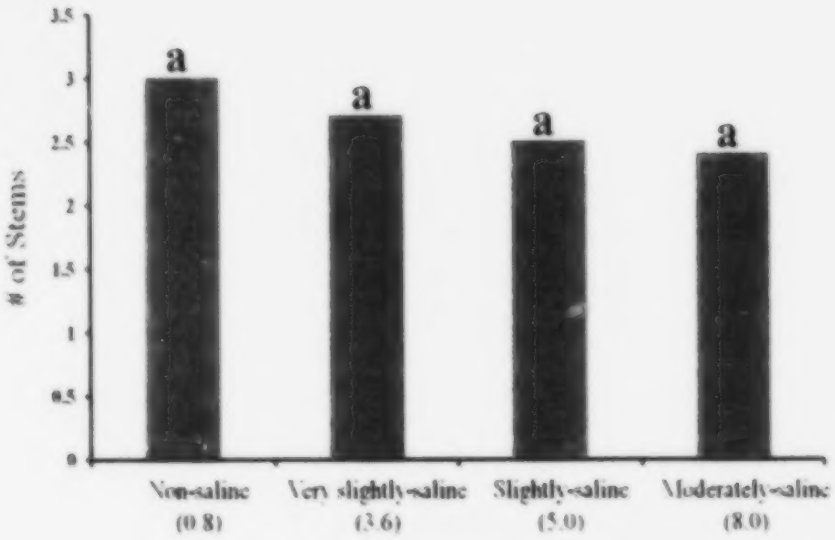

Figure 49. Mean (n = 148) stem count of native and exotic willow grown on soils of varying salinity (dS/m).

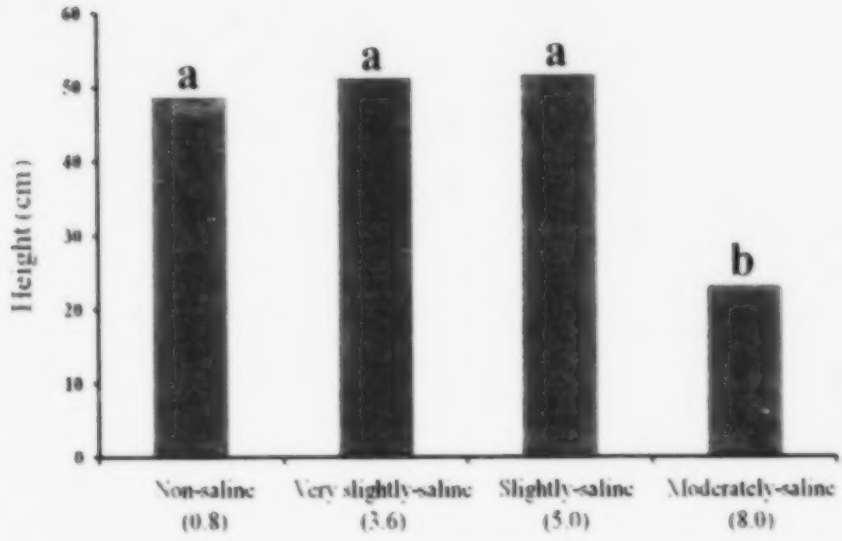

Figure 50. Mean (n = 148) height of native and exotic willow grown on soils of varying salinity (dS/m).

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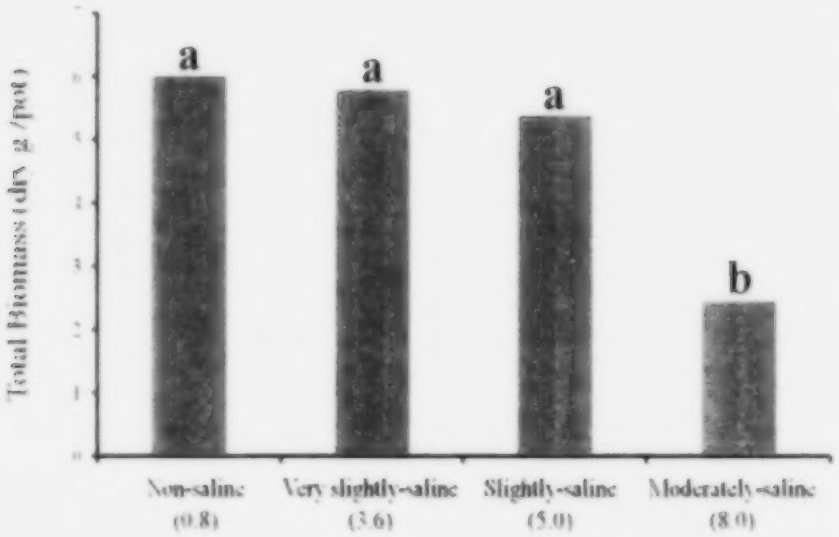

Figure 51. Mean (n = 148) total biomass (shoot + root) of native and exotic willow grown on soils of varying salinity (dS/m).

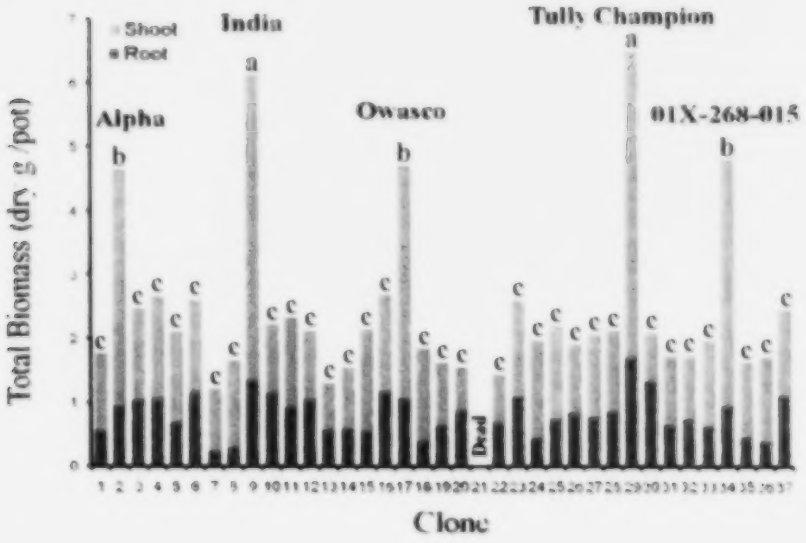

Figure 52. Total biomass (i.e., shoot + root; n = 4) of different native and exotic willow clones grown for 60 days in moderately-saline (8.0 dS/m) soil.

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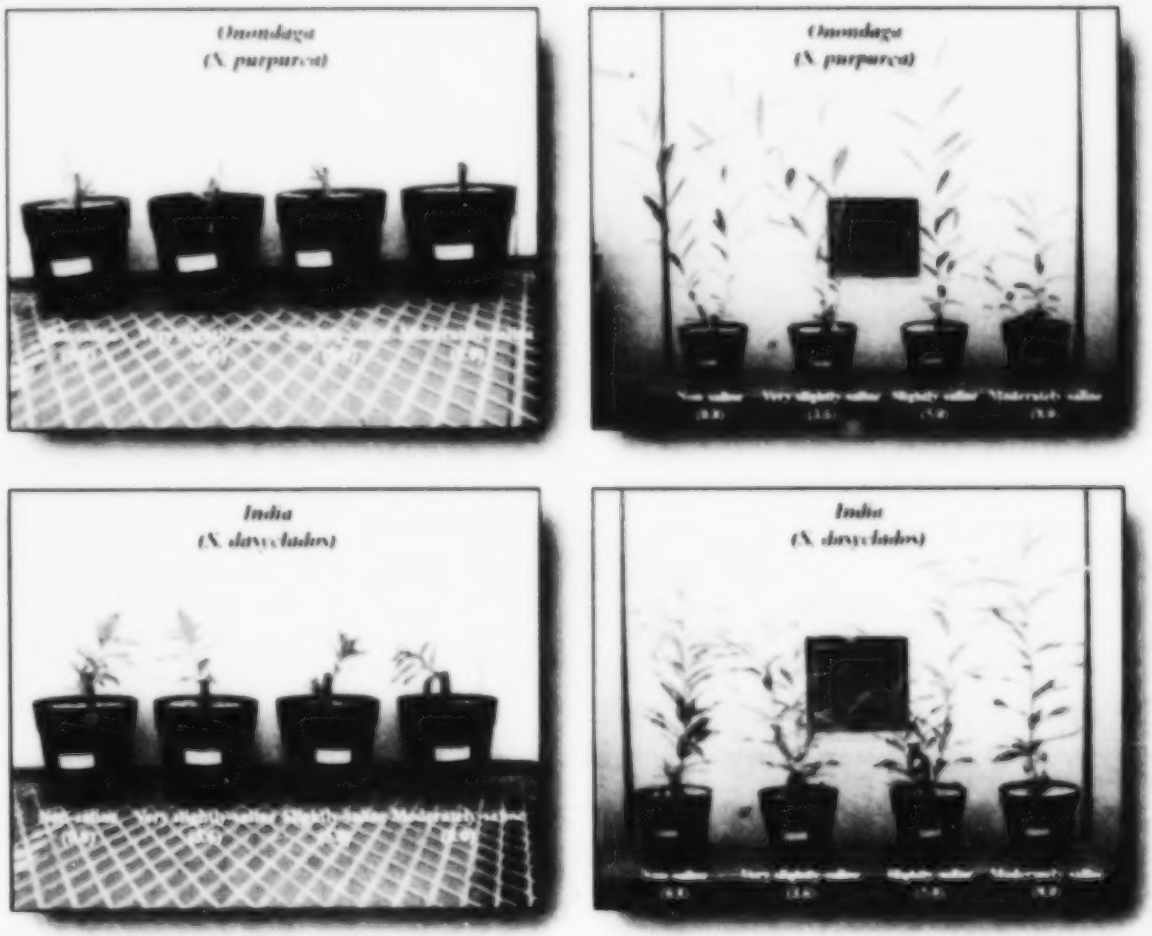

Figure 53. The effect of increasing soil salinity (dS/m) on growth of relatively salt intolerant (Onondaga; above) and tolerant (India; below) willow after 10 (a) and 60 (b) days.

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Table 27. Selected Properties of Saline Soils Used to Screen for Salt Tolerance Among Different Native and Exotic Shrub Willow Species

	Nutrients (mg/kg)				EC (dS/m)			
Soil[§]	NO_3-N	P	K	S	$EC_{1:2}$*	EC_e**	SAR	pH
1	7	19	423	13	0.1	0.8	1.4	7.1
2	8	51	649	295	1.0	3.6	3.4	7.4
3	17	54	657	708	2.0	5.0	4.9	7.6
4	16	40	674	1610	4.0	8.0	9.9	7.9

§ 1 (non-saline), 2 (very slightly-saline), 3 (slightly-saline), 4 (moderately-saline).
* $EC_{1:2}$ – Electrical conductivity of a 1:2 (soil:water) extract.
** EC_e – Electrical conductivity of a saturated paste extract.

5.0 Conclusions and Recommendations

5.1 Hybrid Willow Clonal Trial

The results of this study indicate that willow can be successfully established throughout a broad geoclimatic range in Saskatchewan. The clones used were very robust and demonstrated acceptable survival characteristics, however, these clones will require yields from future rotations to determine their true potential as other studies have shown up to 40% increases in yields between first and second rotations. Insufficient water on very heavy clay soils due to the semi-arid growing season conditions may not make these soils suitable for establishment without additional water. Based on our research trials the ~$7000/ha establishment costs make plantations establishment problematic (Appendix A); however, the cost of planting material accounts for 65% of these costs and with market competition from growers these costs should decrease dramatically. An operation nursery in New York State is selling large quantities of cuttings for ~$0.12/cutting and cuttings in the UK and Sweden sell for ~$0.10/ea . Planting cost in Appendix A are for manual planting and large scale plantings will require mechanized planters which will also reduce costs. However, operational scale plantations are required next to determine potential yields and costs as the costs can be different between research plots and operational scale plantations. Harvesting costs will invariably constitute a large portion of the entire operational budget as well. The successful development of allometric equations, will allow farmers growing these willow clones to reliably estimate above-ground biomass for the first two years

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following coppicing. Further development of this technique is required for the third and final growing season, in case the producer decides that it is economically prudent to wait an additional year prior to harvesting. Additionally, the LAI-2000 Plant Canopy Analyzer appears to be an elegant alternative technique for providing reliable estimates of willow biomass and this work will continue until the end of the rotation as well. Either of these methods will allow growers to efficiently, economically, and effectively assess plantation productivity, for supporting appropriate management decisions in a timely manner.

5.2 Nitrogen Fertilization Trial

Fertilization did not have a significant effect on the production of shoot biomass. The fertilizer was hardly recovered by the trees and was barely evident in the soil at the end of the study period. It is fair to suggest that the N was lost from the system through leaching within the coarse textured soil. Perhaps fertilizers should be applied later in the growth cycle of willow when the root systems become more expansive and the nutrients can be better captured and utilized or at the end of the first rotation. Problems with weed control and herbivory are also issues growers must be aware of and actively manage in order to obtain optimal yields.

5.3 Growth Chamber Fertilization Trial

The growth chamber study supports the results found in the field fertilization trial. Fertilization treatments did not have an effect on the shoot biomass production. It is possible that a longer growth period would be required for distinctions between treatments to emerge. However, shoot biomass differed between soils. This deduces that site selection may be a more important factor than the application of fertilizer. Issues surrounding disease in the growth chamber greatly affected the visual results of the study. Field trials have the advantage of continuous air flow, but combating and managing the health of the trees will still be of the utmost importance for producers.

5.4 Fertilization and Irrigation Trial

The highly significant growth response to irrigation in this study highlights the importance of water in supporting the necessary rates of biomass production that are required to make these bioenergy cropping systems viable. Although there was no fertilization effect after two years with these Class 2 soils, adopting a balanced fertility approach is essential for supporting long-term soil

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productivity, thus providing a sustainable biomass energy production system. Future work needs to examine the influence of agronomic practices (i.e., irrigation and fertilization) on willow biomass feedstock quality, in terms of its suitability for use in specific bioenergy conversion technologies (e.g., anaerobic fermentation, pyrolysis, gasification, or simple combustion) or in manufacturing varied bioproducts (i.e., plastics, adhesives, lubricants, pharmaceuticals, etc.). The principal chemical and physical biomass feedstock properties affecting end use efficiency include: the relative amount and composition of extractives, cellulose, hemicelluloses, and lignin; inorganic element content; specific gravity, calorific energy value; ratio of bark to wood, ash content; and moisture content. Substantial interspecific and interclonal variation in these biomass quality properties exist naturally and, therefore, the potential exists, to not only increase plantation productivity through irrigation and fertilization, but also to accentuate favourable biomass quality characteristics through optimizing soil moisture and nutrient availability under an intensive management regime.

5.5 Salinity Tolerance of Hybrid Willow

Identifying salt-tolerant hybrid willow clones is exciting for a number of reasons. Given the escalating public concern over converting agronomic food crops into fuel crops and/or the displacement of arable land from food production into bioenergy production, a tremendous opportunity exists to develop non-consumable woody crops as a bioenergy feedstock, especially if they can be successfully grown on millions of hectares of marginal land that is deemed unsuitable for annual crop production. Additionally, growing salt-tolerant woody crops would help to revitalize these non-productive agricultural lands in Saskatchewan, which is economically positive for the farmer and may also provide environmental benefits. Further research in the field is required to validate the differences in salt tolerance of willow clones observed in this growth chamber study.

6.0 Acknowledgements

We gratefully acknowledge the contributions of our collaborators, without which this work would not be possible: ADF, CFS, Forest First (formerly the Saskatchewan Forest Centre), Nipawin Biomass Ethanol New Generation Co-operative Ltd., NSERC, PFRA, PRT, SaskPower Shand Greenhouse, SUNY-ESF, University of Saskatchewan willow-planting summer and graduate students, and Western Ag Innovations.

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8.0 Other Aspects

8.1. Communications

The research group utilizes many methods to communicate our project and its findings with research groups, industry as well as society. These included conference talks, academic seminars, website development, publications and field days, which are listed below in detail.

8.1.1 Extension Activities

Hangs, R.D. 2009. Screening for Salt Tolerance in Native and Exotic Shrub Willow. Soil Science Departmental Graduate Seminar Series. November, 30.

Hangs, R.D. and Van Rees, K.C.J. 2007. Centre for Northern Agroforestry and Afforestation Website Development – posting the results to date from this ADF-funded research.

Hangs, R.D. and Van Rees, K.C.J. 2008. Centre for Northern Agroforestry and Afforestation Website Development – posting the results to date from this ADF-funded research.

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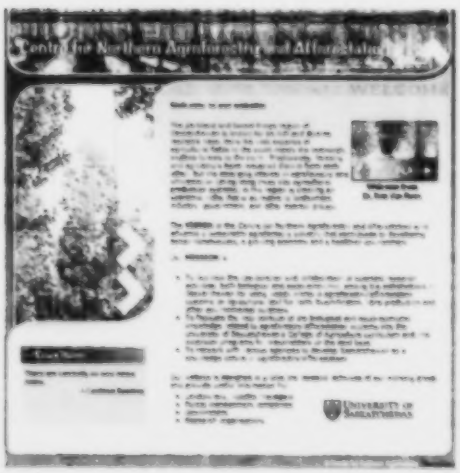

Hangs, R.D., Van Rees, K.C.J., Bélanger, N. and Kort, J. 2007. Environmental Benefits from Agroforestry. Saskatchewan Forest Centre Agroforestry Management Course. Prince Albert, SK.

Hangs, R.D., Van Rees, K.C.J., Bélanger, N. and Kort, J. 2007. Environmental Benefits from Agroforestry. Saskatchewan Forest Centre Agroforestry Management Course. Whitewood, SK.

Hangs, R.D., Van Rees, K.C.J., Bélanger, N. and Kort, J. 2008. Environmental Benefits from Agroforestry. Forest First Agroforestry Management Course. Saskatoon, SK.

Konecsni, S.M. 2008. Fertilization of Willow Bioenergy Cropping Systems in Saskatchewan, Canada. Soil Science Departmental Graduate Seminar Series. March, 2.

Van Rees, K.C.J. 2007. Hosted a Willow Field Day – held in August at the U of S campus to promote the idea of using willow for biomass energy. Guest speakers included Bill Schroeder of AAFC-PFRA Shelterbelt Centre and Derek Sidders of the Canadian Forest Service. The field day was attended by 25 people representing the University, farmers, provincial and federal government agencies, August, 2007.

Van Rees, K.C.J. 2008. Researchers probe willow as a crop. March 6, Western Producer, p. 96.

Van Rees, K.C.J. 2008. Hosted a Willow Field Day – held in August at the U of S campus to promote the idea of using willow for biomass energy. Guest speakers included Derek Sidders of the Canadian Forest Service. The field day was attended by 40 people representing the University, farmers, provincial and federal government agencies. Subsequently, an article highlighting the field day appeared in the Star Phoenix.

Van Rees, K.C.J. 2008. Tour of willow plantations provided to John Kitchen (Vice President, Business Development Pacific Regeneration Technologies Inc.), November 2008.

Van Rees, K.C.J. 2009. Tour of willow plantations provided to John Doornbos and Deb Brenton (Poplar Council of Canada), Cees van Oosten (SilviConsult Woody Crops Technology Inc.), and Al Jurgens (Canadian Forest Service), September 2008.

8.1.2 Book Chapters

Kulshreshtha, S.N., Van Rees, K.C.J., Hesseln, H., Johnston, M., and Kort, J. 2009. Issues in Agroforestry Development on the Canadian Prairies, In L.R. Kellimore (*ed*), Handbook on Agroforestry: Management Practices and Environmental Impact, Nova Science Publishers, Inc. Hauppauge NY (accepted, June 3, 2009).

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8.1.3 Papers Produced

Amichev, B.Y., M. Johnston and K.C.J. Van Rees. 2009. Hybrid poplar growth in bioenergy production systems: Biomass prediction with a simple process-based model (3PG). Biomass Bioenergy (accepted Sept 2009)

Amichev, B.Y, Hangs, R.D., Van Rees, K.C.J. 2009. A novel approach to simulate growth of multi-stem willow in bioenergy production systems with a simple process-based model (3PG). Biomass and Bioenergy (in review).

Ens, J. and Bélanger, N. 2009. Rapid biomass estimation using optical stem density of willow (*Salix* spp.) grown in short rotation. Biomass Bioenerg. 33: 174-179.

Hangs, R.D., Van Rees, K.C.J., Schoenau, J.J., Guo, X. 2009. A Simple Technique for Estimating Above-ground Biomass in Short-Rotation Willow Plantations. Biomass and Bioenergy (in review).

Hangs, R.D., Van Rees, K.C.J., and Schoenau, J.J. 2009. Examining the salt tolerance of willow bioenergy species for use on salt-affected agricultural lands. Biomass and Bioenergy (in preparation).

Van Rees, K.C.J. 2007. Establishment of Willow species in Saskatchewan. Final Report Saskatchewan Forest Centre.

Van Rees, K.C.J. 2008. Developing a national agroforestry and afforestation network for Canada. Policy Options 29:54-57.

8.1.4 Conference Presentations Made

Amichev, B. and Van Rees, K.C.J. 2008. Predicting Hybrid Poplar Growth with a Simple Process-based Model (3PG). Biofuels, Bioenergy and Bioproducts from Sustainable Agricultural and Forest Crops. Short Rotation Crops International Conference, August 19-21, Bloomington, Minnesota.

Amichev, B. and Van Rees, K.C.J. 2009. A Novel Approach to Simulate Growth of Multi-Stem Willow Species with a Simple Process-Based Model (3PG). Willow Crops: Research and Opportunity Conference, March 17-18, Saskatoon, Saskatchewan.

Amichev, B., Kurz, W.R., and Van Rees, K.C.J. 2009. Carbon Budget of Agricultural Land following Afforestation with Willow for Bioenergy Production: A CBM-CFS3 Model Simulation. Willow Crops: Research and Opportunity Conference, March 17-18, Saskatoon, Saskatchewan.

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8.2 Personnel Involved

Ken Van Rees – Principle Investigator, University of Saskatchewan

Doug Jackson – Research Technician, University of Saskatchewan

Beyhan Amichev – Postdoctoral Fellow, University of Saskatchewan

Ryan Hangs – Ph.D. Student, University of Saskatchewan

Sheala Konecsni – M.Sc. Student, University of Saskatchewan

Summer Students – Cassandra Lasko, Terri Lynn, Paulson, Christine Stadnyk (current NSERC M.Sc. Student), Melissa and Rachel Van Rees, Josh Leventhal, and Amber Jones

8.3 Photos

For an extensive assortment of photographs from all four hybrid willow plantations, please visit the ***Biomass Energy Crop Trials*** webpage located on the **Centre for Northern Agroforestry and Afforestation** website at the following address:

http://www.saskagroforestry.ca/index.php?pid=904

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Willow Field Day 2007

Signage 2007

Trying to stay dry

Derek Sidders (CFS) talking about the 7 willow clones and their willow program

A rather wet day

Clay and water = mud

Participants

Gathering of the group

Bill Schroeder talking about the willow common garden

Ken addressing the group

Ken Van Rees

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Doug Jackson on left

John Kort and Derek looking at some hybrid poplar

Sheala Konecsni

New willow clones from SUNY

Participants

V. Vujanovic talking about work with pathogens

Rick Block (Heifer) inspecting willow

Walking out to plots

Vladimir interacting with group

Casandra and signage

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Willow Field Day 2008

The equipment

Robert Grant (U of A)

Common willow garden

The heipers with new rototiller

Participants

Ryan Hangs talking about his research

Melissa, Sheala and Rachel

Ken talking about common willow garden plots

Ken explaining CFS trial

Talking herbicides

Common willow garden

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Participants

Participants

Sheala talking about her fertilizer study

Field days are fun too

Derek Sidders (CFS) talking about willow

Willow sawfly infestation

Rich Farrell talking about GHG

Derek Sidders

Christine Stadnyk talking about root systems

Rich Farrell

Participants

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Christine and minirhizotron

Participants

The sound system carrier

Sheala

Christine and minirhizotron

Participants

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Willow Field Day 2009

Ryan Hangs discussing his research on irrigation

Wet conditions again

Participants

Alain talking about his willow molecular marking project

Joel Ens discussing his research on GHG

Participants

Chistine Stadnyk talking about her root project

Delegation from Rural Generation, Ireland

John Gilliland (Chairman), Malcolm Dawson and Chris Johnston from Rural Generation

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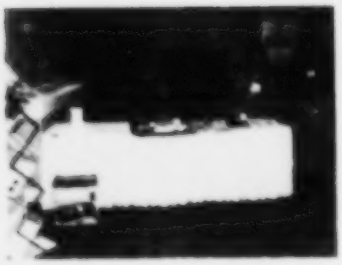
Willow Conference 2009

Participants

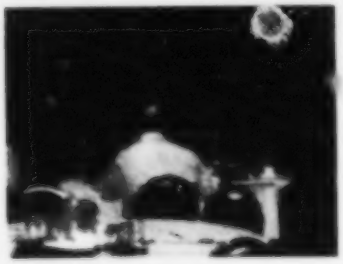
Posters



ForestFirst folks handling registrations

Christine, Ryan and Sheala

Keynote speaker John Farrell from Scotland



Lunch break

Participants

Conference room

Keynote speaker Håkan Rosenqvist from Sweden

Posters

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Willow clones in pots

Participants

Participants

Guest speaker Naresh Thevathasan from Univ. of Guelph

Ken Van Rees (Co-chair; left), Håkan, John and Robin Woodward (ForestFirst, Co-chair)

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9.0 Appendices

9.1 Appendix A. Approximate cost to establish a willow plantation

Site Preparation	
Cultivation	$10/ha
Pre emergent herbicide (Treflan/Sencor)	$70.97/ha
Planting	
Cuttings ($.30/cutting)*	$4400/ha
Planting (14,376 cuttings/ha)	$2200/ha
Weed Maintenance (Year 1)	
Herbicide (2 applications of glyphosate between beds)	$78/ha
Insecticide	
Insecticide (Decis) if required	$6.10/ha
Total	$6765.07/ha

* Currently this is the price for willow cuttings in Saskatchewan but as the industry develops other countries have indicated that this price has come down to about $0.10 per cutting. The Double A Willow nursery in New York currently sells cuttings for about $0.12 on large scale orders. Once farmers have established their own plantations, they will be able to harvest their own cuttings for planting material at no cost. Planting costs can also be reduced with a mechanical planter.

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9.2 Appendix B. Selected environmental data collected over three years at the willow plantation near Birch Hills, Saskatchewan.

Month	Total Rain	RH	Par	Air Temp	Max Air Temp	Min Air Temp	Soil Temp 10 cm	Soil Temp 20 cm	Soil temp 30 cm	Soil temp 50 cm	Soil Temp 70 cm
	mm	%	µmol/m²/s			°C					
						2007					
July	48.8	73.6	272.9	21.2	27.2	14.9	22.1	20.5	19.9	17.8	16.3
August	66.1	78.7	196.9	14.9	21.2	8.8	16.8	16.2	16.5	16.0	15.5
September	27.5	79.0	132.1	9.6	16.6	3.5	11.7	11.2	11.9	12.1	12.1
October	12.5	78.6	81.6	4.7	10.6	-0.6	6.4	5.8	6.8	7.5	8.0
November	4.3	83.5	39.9	-7.3	-3.3	-12.4	1.6	0.7	1.8	2.9	3.6
December	0.0	86.5	31.9	-16.3	-12.2	-21.3	1.4	-0.3	0.6	1.4	1.9
						2008					
January	0.0	82.8	40.4	-16.6	-11.6	-22.9	1.0	-0.6	0.2	0.9	1.3
February	1.2	78.2	85.1	-17.8	-11.8	-25.5	0.4	-1.3	-0.4	0.3	0.7
March	2.8	79.8	157.6	-8.8	-2.4	-15.9	0.6	-1.2	-0.6	0.0	0.3
April	17.5	71.3	203.1	0.5	6.5	-5.2	1.6	-0.7	-0.3	0.0	0.2
May	9.1	52.8	269.7	10.3	17.7	1.9	9.8	5.9	5.1	4.0	3.1
June	30.2	60.3	267.8	16.0	23.3	7.6	18.4	14.8	14.1	13.4	10.8
July	95.5	78.2	239.2	17.2	23.9	10.9	19.9	16.4	16.2	16.7	13.9
August	27.5	75.4	210.7	17.0	24.8	9.7	19.1	15.8	16.0	17.0	14.5
September	25.3	71.6	132.0	10.3	18.8	2.4	13.8	11.0	11.8	13.5	11.9
October	22.1	69.5	64.6	5.4	12.5	-1.4	8.7	6.4	7.4	9.4	8.5
November	6.9	87.2	34.5	-3.9	0.2	-8.9	3.1	0.9	2.1	4.1	4.0
December	0.5	79.0	30.1	-21.4	-16.9	-26.7	-0.6	-2.5	-0.9	1.1	1.2
						2009					
January	10.7	79.4	43.7	-17.9	-13.1	-24.0	-2.4	-3.0	-1.8	-0.3	-0.2
February	1.4	80.6	85.9	-15.8	-9.5	-22.2	-2.0	-2.4	-1.6	-0.4	-0.5
March	2.7	78.3	162.0	-11.4	-5.1	-18.1	-1.8	-2.3	-1.6	-0.4	-0.7
April	0.0	79.1	231.2	-2.5	5.3	-9.9	-0.7	-1.3	-1.0	-0.1	-0.6
May											
June						Problems with datalogger					
July											
August	1.6	76.6	181.2	15.7	23.3	7.6	16.6	13.0	13.3	18.5	12.2

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9.3 Appendix C. Selected environmental data collected over three years at the willow plantation near Estevan, Saskatchewan.

Month	Total Rain	RH	Par	Air Temp	Max Air Temp	Min Air Temp	Soil Temp 10 cm	Soil Temp 20 cm	Soil temp 30 cm	Soil temp 50 cm	Soil Temp 70 cm
	mm	%	µmol/m^2/s				°C				
						2007					
July	27.2	64.5	275.9	23.1	31.1	15.0	25.5	25.0	24.1	22.0	20.1
August	16.4	65.5	219.9	17.9	25.9	9.5	21.9	21.7	21.6	21.0	20.3
September	13.0	62.0	166.1	13.1	21.6	4.1	16.6	16.5	16.7	16.7	16.6
October	49.4	75.5	100.7	7.3	13.6	1.1					
November	3.7	70.8	55.0	-3.2	2.5	-9.6		Problems with datalogger			
December	0.5	82.8	45.4	-12.4	-5.7	-20.0	-4.8	-4.4	-3.3	-1.2	0.7
						2008					
January	0.3	78.4	59.8	-13.2	-6.0	-21.0	-6.8	-6.4	-5.3	-3.4	-1.5
February	4.0	79.3	101.1	-13.0	-5.6	-20.8	-7.2	-6.9	-6.2	-5.0	-3.5
March	12.9	76.9	145.0	-3.8	2.8	-10.9	-1.7	-1.7	-1.7	-1.7	-1.5
April	5.0	57.4	215.5	4.6	12.6	-4.0	3.9	3.1	2.3	0.7	-0.3
May	49.2	54.7	251.5	10.8	18.3	1.9	11.5	10.2	9.4	7.4	5.2
June	53.6	67.8	256.5	15.4	22.2	7.7	18.1	16.1	15.7	14.1	12.3
July	39.6	64.1	283.7	19.7	27.6	11.0	25.5	22.1	21.6	20.1	18.1
August	64.1	63.9	241.2	19.6	27.8	10.7	25.2	22.1	22.0	21.2	19.5
September	71.6	73.4	163.7	11.9	20.2	4.0	17.8	15.3	15.6	16.1	15.4
October	35.2	68.8	105.7	5.4	13.3	-2.2	10.3	8.1	8.8	10.2	10.3
November	9.3	79.1	53.9	-1.7	4.5	-7.8	2.2	1.5	2.3	4.0	4.7
December	3.0	79.2	44.5	-16.5	-10.8	-22.9	-2.6	-2.5	-1.6	0.1	1.0
						2009					
January	3.6	79.5	65.3	-16.4	-10.2	-23.7	-1.7	-1.8	-1.3	-0.4	0.1
February	0.2	81.6	106.5	-14.2	-8.2	-21.9	-0.8	-0.9	-0.7	0.0	0.1
March	10.2	80.4	166.1	-7.6	-1.3	-14.8	-0.4	-0.6	-0.3	0.2	0.3
April	37.4	70.1	196.3	4.2	10.3	-2.2	5.5	4.2	4.0	3.7	2.8
May	5.1	56.9	252.1	10.9	18.7	0.9	16.4	13.4	12.8	11.8	9.7
June	48.7	66.5	263.4	15.8	23.3	7.4	20.2	17.2	16.9	16.2	14.0
July	69.7	70.0	257.1	17.1	24.5	8.7	21.0	18.4	18.2	17.9	15.8
August	79.9	72.2	201.5	17.4	25.7	9.4	19.9	17.6	17.5	17.6	15.7

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9.4 Appendix D. Selected environmental data collected over three years at the willow plantation near Prince Albert, SK.

Month	Total Rain	RH	Par	Air Temp	Max Air Temp	Min Air Temp	Soil Temp 10 cm	Soil Temp 20 cm	Soil temp 30 cm	Soil temp 50 cm	Soil Temp 70 cm
	mm	%	µmol/m^2/s				°C				
						2007					
July	34.0	69.3	279.8	21.8	28.6	14.3	23.9	23.3	22.3	20.8	19.1
August	82.3	77.6	190.6	14.4	20.6	8.3	17.2	17.4	17.3	17.2	17.1
September	47.5	80.4	121.8	8.9	15.8	2.8	11.1	11.8	11.5	11.9	12.3
October	16.1	78.9	75.3	4.2	10.1	-0.8	5.6	6.6	6.2	6.9	7.7
November	8.0	83.8	28.0	-7.9	-3.9	-12.7	0.5	1.5	1.2	2.1	3.1
December	0.0	85.4	19.7	-16.5	-12.4	-21.5	0.3	1.3	0.7	1.2	1.9
						2008					
January	1.5	81.4	32.8	-17.3	-11.9	-24.2	0.3	1.3	0.5	0.9	1.5
February	8.3	74.8	77.5	-18.3	-11.3	-26.4	0.2	1.3	0.4	0.7	1.2
March	2.1	73.9	146.0	-8.8	-0.9	-17.0	0.2	1.4	0.3	0.5	1.0
April	15.9	65.6	197.4	0.5	6.7	-5.5	2.2	3.9	1.8	1.4	1.6
May	9.8	53.5	273.1	9.9	17.2	1.8	15.8	16.0	10.3	10.8	9.8
June	30.7	62.2	267.3	15.3	22.8	6.4	20.4	19.8	16.7	15.4	14.9
July	48.0	74.9	231.5	17.3	23.8	10.8	21.6	20.2	17.7	16.4	16.3
August	25.4	72.2	191.8	16.9	24.6	8.9	21.9	21.1	17.9	17.0	17.4
September	11.1	75.6	81.2	7.9	15.4	0.6	13.4	13.2	10.3	10.6	11.8
October	18.5	72.2	54.1	4.2	11.2	-2.4	8.9	8.8	5.8	6.7	8.0
November	9.9	86.1	28.1	-4.5	-0.4	-9.2	3.7	3.6	1.0	1.9	3.2
December	0.7	77.0	20.8	-21.8	-16.9	-27.1	-0.6	-0.3	-2.4	-0.6	0.7
						2009					
January	1.6	75.1	42.8	-15.2	-8.5	-21.5	-6.6	-5.9	-6.0	-5.1	-4.5
February	Problems with datalogger										
March	12.2	70.2	147.6	-10.5	-2.8	-18.6	-2.6	-2.2	-2.2	-1.4	-1.2
April	5.3	65.5	206.1	2.0	9.2	-5.2	2.9	3.6	2.0	1.9	1.5
May	44.4	59.7	232.4	7.6	15.4	-1.0	10.2	12.6	9.4	8.0	7.9
June	59.8	68.0	217.5	14.2	21.9	5.8	16.8	18.6	8.1	13.6	13.6
July	69.1	74.2	166.8	15.5	22.2	8.1	19.3	21.3	6.8	15.4	15.9
August	54.1	78.2	95.4	14.6	21.5	7.6	19.0	24.9	17.4	14.8	16.3

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9.5 Appendix E. Selected environmental data collected over three years at the willow plantation in Saskatoon, SK.

Month	Total Rain	RH	Par	Air Temp	Max Air Temp	Min Air Temp	Soil Temp 10 cm	Soil Temp 20 cm	Soil temp 30 cm	Soil temp 50 cm	Soil Temp 70 cm
	mm	%	µmol/m^2/s			°C					
						2007					
July	20.4	62.8	284.4	21.9	27.7	15.2	22.7	21.4	20.6	18.6	16.8
August	107.2	66.5	198.4	16.3	22.4	10.5	18.6	18.5	18.6	18.3	17.9
September	25.8	69.1	145.6	11.1	17.4	5.0	13.7	13.8	14.2	14.5	14.7
October	14.0	72.5	97.8	5.6	11.5	0.3	7.1	7.5	8.2	9.1	9.9
November	6.2	75.4	50.4	-4.8	-0.5	-8.9	1.3	2.0	2.8	4.1	5.3
December	1.2	84.8	35.7	-14.2	-10.9	-17.8	-2.5	-2.1	-1.5	-0.3	0.8
						2008					
January	0.5	81.5	48.0	-14.4	-9.3	-19.4	-3.2	-2.8	-2.3	-1.3	-0.3
February	0.5	78.3	93.6	-15.3	-9.7	-20.9	-4.8	-4.5	-3.9	-2.8	-1.7
March	1.1	78.4	149.4	-5.2	-0.2	-10.2	-1.9	-2.0	-1.9	-1.7	-1.5
April	16.0	65.8	194.2	2.0	7.8	-3.9	1.3	0.4	0.0	-0.6	-0.7
May	3.4	46.4	269.9	11.7	18.3	4.2	10.8	9.4	8.3	6.1	4.2
June	56.7	60.5	252.6	16.0	22.3	9.0	16.1	15.5	14.3	12.8	11.5
July	66.0	67.9	250.7	18.4	24.4	12.3	19.5	19.6	18.0	16.6	15.5
August	29.0	60.9	227.2	18.6	25.9	11.6	19.7	20.1	18.4	17.5	17.0
September	13.7	64.1	167.0	11.8	19.6	4.9	13.7	14.0	13.7	14.0	14.4
October	47.3	63.6	93.6	6.1	12.4	0.2	7.1	7.8	8.2	9.2	10.3
November	6.7	80.3	42.9	-1.7	2.5	-5.9	2.6	3.3	3.8	5.0	6.2
December	0.0	77.9	35.8	-18.9	-14.5	-23.3	-6.8	-5.8	-4.7	-2.4	-0.5
						2009					
January	10.3	77.0	52.3	-15.8	-10.7	-21.2	-4.0	-3.7	-3.2	-2.3	-1.3
February	0.5	80.1	92.9	-14.2	-9.1	-19.3	-3.4	-3.2	-2.9	-2.2	-1.5
March	1.3	77.8	159.2	-9.5	-3.8	-15.6	-2.9	-2.8	-2.6	-2.1	-1.6
April	2.4	63.1	201.9	3.3	9.3	-2.8	3.4	2.7	1.8	0.7	-0.1
May	12.1	51.7	239.5	9.7	16.5	2.4	11.8	10.9	9.6	7.9	6.5
June	51.5	56.0	252.2	16.2	22.5	9.2	17.2	16.7	15.4	13.9	12.6
July	54.2	66.9	230.4	16.8	22.9	10.2	17.8	17.5	16.5	15.5	14.8
August	83.7	70.0	193.9	16.5	23.0	10.4	17.4	17.2	16.4	15.7	15.7

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9.6 Appendix F. Examples of posters presented at scientific conferences and workshops.

A Novel Approach to Simulate Growth of Multi-Stem Willow Species with a Simple Process-Based Model (3PG)

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B. [illegible] Stadnyk, N. [illegible], J. [illegible] Reid and R. [illegible] Hangs

University of Saskatchewan, Department of Soil Science, Saskatoon, Canada

Introduction

3PG (Physiological Principles in Predicting Growth) model

- [illegible]
- [illegible]
- [illegible]

SV1 willow clone

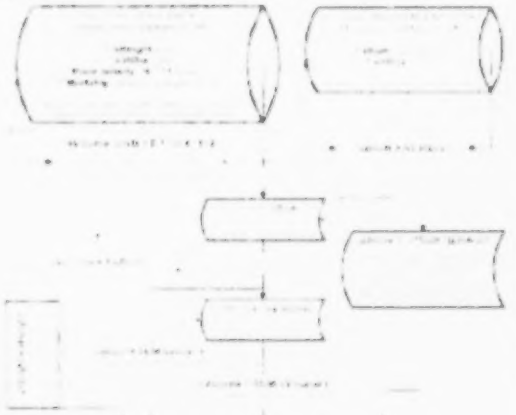
- [illegible]
- [illegible]
- [illegible]
- [illegible]

Main objectives:

1. [illegible]
2. [illegible]

Materials and Methods

[illegible]



Data sources:

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- [illegible]
- [illegible]
- [illegible]
- [illegible]
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Conceptual model for plant-level data analysis:

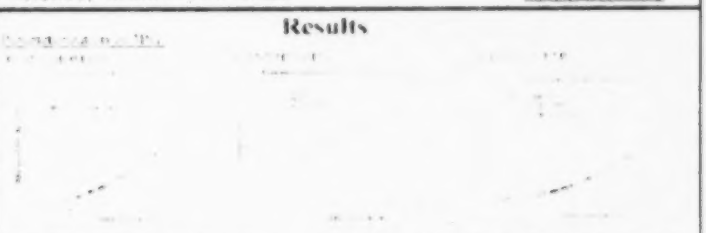
- [illegible]
- [illegible]
- [illegible]
- [illegible]

3PG model parameterization for SV1 willow clone:

- [illegible]

Results

[illegible]



3PG simulation of SV1 growth:

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Input variables affecting 3PG model predictions:

- [illegible]
- [illegible]
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Summary

- [illegible]
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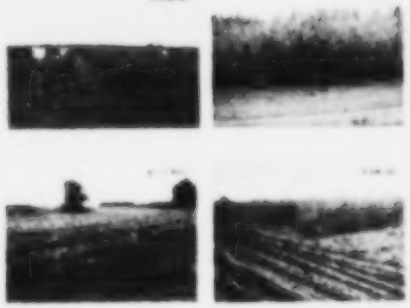
First year growth results after coppicing for willow plantations at four sites in Saskatchewan

Doug Jackson[1] Beyhan Amichev[1] Tim Volk[2] and Ken Van Rees[1] [1]Department of Soil Science University of Saskatchewan [2]SUNY-ESF

Introduction

Material and Methods



Results

Conclusions

Acknowledgements

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Screening Salt Tolerance in Willow

Ryan Hangs*, Ken Van Rees, and Jeff Schoenau

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INTRODUCTION

A growing desire worldwide for a renewable and environmentally friendly source has fueled interest in purpose-grown biomass for bioenergy production.

Short rotation woody crops (SRWC) are fast growing species that can be harvested on a regular basis (3-5 years) for biomass production. Willow (*Salix* spp.) is a SRWC that has been identified as a potential candidate for bioenergy production in Saskatchewan.

Salinity is a significant environmental problem across the Canadian prairies. It is estimated that 1.6 million ha of cultivated land in Saskatchewan alone is affected by salinity and sodicity. Salt tolerance information for willow species is limited.

OBJECTIVE

Determine the salt tolerance of numerous native and exotic willow species for their potential use in willow phytoremediation to treat saline and sodic-affected soils.

MATERIALS & METHODS

Numerous *Salix* species and cultivars were collected from across Saskatchewan and established in a greenhouse trial using deep (1 m) containers filled with a Dark Brown Chernozemic soil. Plants were irrigated with a 0, 50, 100, 150, 200, 250, 300, 350, 400, 450, and 500 mM NaCl solution (Table 1). Plant height and stem diameter were measured after 16 days of salt treatment.

Figure 1. Establishing and measuring willow cuttings in the greenhouse trial. Cuttings were established in deep containers filled with a Dark Brown Chernozemic soil (left), salt treatments were applied (middle), and plant height and stem diameter were measured after 16 days (right).

Table 1. Selected native willow species and cultivars screened for salt tolerance.

Species	Cultivar	Origin
Salix bebbiana		Native
Salix discolor		Native
Salix eriocephala		Native
Salix exigua		Native
Salix interior		Native
Salix lucida		Native
Salix lutea		Native
Salix petiolaris		Native
Salix prolixa		Native
Salix pseudomonticola		Native
Salix purpurea		Native
Salix purpurea	Hotel	Exotic
Salix purpurea	Inko	Exotic
Salix purpurea	Otter	Exotic
Salix purpurea	Rosyam	Exotic
Salix purpurea	Streamco	Exotic
Salix purpurea	Tora	Exotic
Salix purpurea	Vimco	Exotic
Salix purpurea	Vimco Select	Exotic
Salix purpurea	Vimco Select 2	Exotic
Salix purpurea	Vimco Select 3	Exotic
Salix purpurea	Vimco Select 4	Exotic
Salix purpurea	Vimco Select 5	Exotic
Salix purpurea	Vimco Select 6	Exotic
Salix purpurea	Vimco Select 7	Exotic
Salix purpurea	Vimco Select 8	Exotic
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Salix purpurea	Vimco Select 96	Exotic
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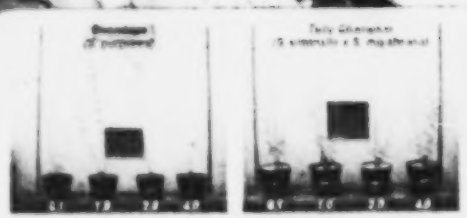

Figure 2. The effect of increasing salt concentration on stem diameter and height of willow cuttings after 16 days of salt treatment.

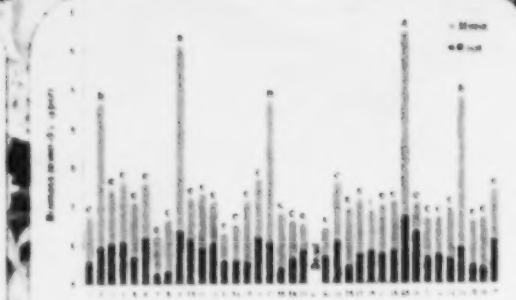

Figure 3. Biomass of different native and exotic willow species after 16 days of salt treatment. See Table 1 for species and cultivar information. Bars with the same letters are not significantly different (P<0.05).

CONCLUSIONS

Thanks to the Saskatchewan Ministry of Agriculture for the funding. Special thanks to Jennifer Pfeiffer and Timothy Wilk for their assistance in the greenhouse and to Dr. Patrick Hall for his statistical support.

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Evaluating Different Techniques for Estimating Biomass in Short-Rotation Willow Plantations

Ryan Hanga, Ken Van Rees, and Jeff Schoenau

Department of Soil Science, University of Saskatchewan, Saskatoon, SK S7N 5A2

INTRODUCTION

- Considering that harvesting operations are the greatest single cost incurred with short-rotation intensive culture willow production systems, it is imperative for farmers to optimize the timing of harvest. Best harvest decisions are based on accurate estimations of current yield and support the greatest economical return on investment.
- Monitoring annual production rates is useful in making effective management decisions prior to harvest, such as the need for fertilization and pest control, to increase plantation productivity.
- It is prudent, therefore, to develop a simple, rapid, cost effective, and non-destructive technique that provides reliable biomass estimates to support effective management decisions in a timely manner.

OBJECTIVE

Compare a conventional allometric technique (defined by a simple empirical relationship between stem size and mass, Fig 1a) with a novel alternative method measuring light attenuation through the willow crop canopy (Fig. 1b).

Figure 1. Estimating above-ground willow biomass using an allometric technique (a) and a LI-COR 2000 Plant Canopy Analyzer to measure the gap fraction corresponding to five sample rings located on different willow stages (b).

MATERIALS & METHODS

- The data were collected from a two-year old hybrid willow clone that setup in a randomized nonbalanced block design and replicated three times. Two clones with contrasting growth form were studied: Charlie (single stem) and SV1 (multi-stem).
- Traditional allometric equations for estimating above-ground willow biomass were developed by calibrating measured stem diameter (at 30 cm height; Fig. 1a) with harvested biomass from 30 systematically sampled plants of each clone.
- A LAI-2000 Plant Canopy Analyzer (LI-COR Inc., Lincoln, NE) was used to measure the gap fraction (i.e., the fraction of sky visible from beneath the canopy that is not blocked by stems or branches, Fig. 1b) for leafless willow within each block. The Leaf Area Index calculated therefore, provided a 'Stem Area Index' measure for calibrating with harvested biomass.

RESULTS

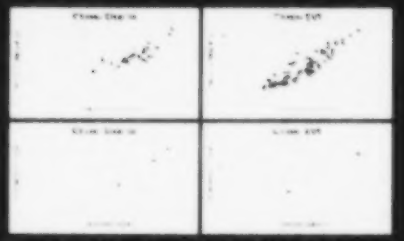

Figure 2. Relationship between above-ground biomass of different willow clones using an allometric relationship between stem diameter (30 cm height) and leafless stem weight of 30 systematically sampled plants (a and b) or measuring Stem Area Index measured using a LI-COR 2000 Plant Canopy Analyzer, with harvested and destructive (c and d).

DISCUSSION & CONCLUSIONS

- The allometric relationships in this study were not as robust as those typically reported in the literature for willow (r^2 values ~ 0.96). These relatively poor models are probably due to the uncoppiced management of the study plantation. Coppicing promotes the production of larger numbers of uniformly-shaped stems (i.e., relatively homogeneous diameter:mass), which also helps to explain the observed larger R^2 value of the multi-stemmed SV1 clone allometric model compared to the single-stemmed Charlie model.
- Given the strong correlation between Stem Area Index, measured using the LAI-2000 Plant Canopy Analyzer, and above-ground biomass of the two hybrid willow clones, it appears that this novel measurative technique is a promising alternative to conventional allometry, thereby supporting effective management decisions throughout the rotation of purpose-grown hybrid willow plantations.
- Further research is needed to determine if the observed relationships between Stem Area Index and biomass exist with different clones growing across a geoclimatic gradient, on a variety of soil types, under a coppiced management system typically used in the US and Europe.

ACKNOWLEDGEMENTS

Many thanks to the Saskatchewan Ministry of Agriculture for funding this research; D. Sidders (Canadian Forest Service) for providing the field site; X. Guo for supplying the LAI-2000; B. Amichev, D. Jackson, S. Konecsni, and C. Stadnyk for their help in the field; and, T. Demetriades-Shah (LI-COR Inc.) for his technical assistance.

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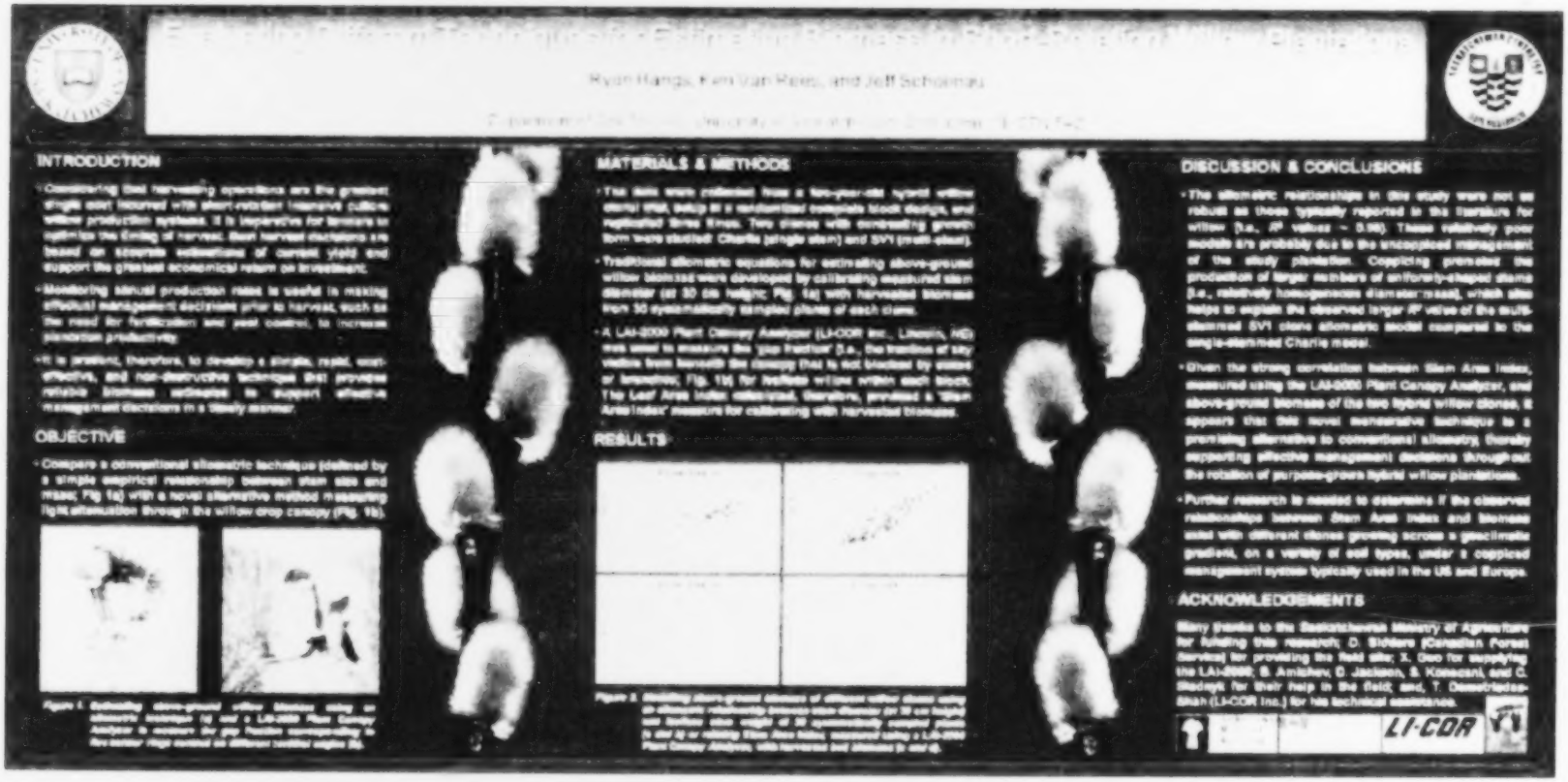

Ryan Hangs, Ken Van Rees, and Jeff Schoenau

INTRODUCTION

- Considering that harvesting operations are the greatest single cost incurred with short-rotation intensive cultivar willow production systems, it is imperative for farmers to optimize the timing of harvest. Stem harvest durations are based on accurate estimations of current yield and support the greatest economical return on investment.
- Monitoring stand production rates is useful in making effective management decisions prior to harvest, such as the need for fertilization and pest control, to increase plantation productivity.
- It is prudent, therefore, to develop a simple, rapid, cost-effective, and non-destructive technique that provides reliable biomass estimates to support effective management decisions in a timely manner.

OBJECTIVE

- Compare a conventional allometric technique (defined by a simple empirical relationship between stem size and mass; Fig 1a) with a novel alternative method measuring light attenuation through the willow crop canopy (Fig. 1b).

Figure 1. Estimating above-ground willow biomass using an allometric technique (a) and a LAI-2000 Plant Canopy Analyzer to measure the gap fraction corresponding to the sensor rings nested at different zenithal angles (b).

MATERIALS & METHODS

- Tree data were collected from a two-year-old hybrid willow stems trial, setup in a randomized complete block design, and replicated three times. Two clones with contrasting growth form were studied: Charlie (single stem) and SV1 (multi-stem).
- Traditional allometric equations for estimating above-ground willow biomass were developed by calibrating measured stem diameter (at 30 cm height; Fig. 1a) with harvested biomass from 30 systematically sampled plants of each clone.
- A LAI-2000 Plant Canopy Analyzer (LI-COR Inc., Lincoln, NE) was used to measure the 'gap fraction' (i.e., the fraction of sky visible from beneath the canopy that is not blocked by stems or branches; Fig. 1b) for multiple willow within each block. The Leaf Area Index calculated, therefore, provided a "Stem Area Index" measure for calibrating with harvested biomass.

RESULTS

Figure 2. Modelling above-ground biomass of different willow clones using an allometric relationship between stem diameter (at 30 cm height) and dry mass (g) of 30 systematically sampled plants (a and b) or relating Stem Area Index, measured using a LAI-2000 Plant Canopy Analyzer, with harvested biomass (c and d).

DISCUSSION & CONCLUSIONS

- The allometric relationships in this study were not as robust as those typically reported in the literature for willow (i.e., R^2 values ~ 0.90). These relatively poor models are probably due to the uncoppiced management of the study plantation. Coppicing promotes the production of larger numbers of uniformly-shaped stems (i.e., relatively homogeneous diameter-mass), which also helps to explain the observed larger R^2 value of the SV1-stemmed SV1 clone allometric model compared to the single-stemmed Charlie model.
- Given the strong correlation between Stem Area Index, measured using the LAI-2000 Plant Canopy Analyzer, and above-ground biomass of the two hybrid willow clones, it appears that this novel nonexpensive technique is a promising alternative to conventional allometry, thereby supporting effective management decisions throughout the rotation of purpose-grown hybrid willow plantations.
- Further research is needed to determine if the observed relationships between Stem Area Index and biomass exist with different clones growing across a geoclimatic gradient, on a variety of soil types, under a coppiced management system typically used in the US and Europe.

ACKNOWLEDGEMENTS

Many thanks to the Saskatchewan Ministry of Agriculture for funding this research; D. Sidders (Canadian Forest Service) for providing the field site; X. Dao for supplying the LAI-2000; S. Amrahov, D. Jackson, & Kinnecom, and C. Bladyski for their help in the field; and, T. Demetriades-Shah (LI-COR Inc.) for his technical assistance.

LI-COR

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Fertilization of willow bioenergy cropping systems in Saskatchewan, Canada

Sheala Konecsni and Ken Van Rees
Department of Soil Science University of Saskatchewan

Introduction

We are first growing tree species that require adequate amounts of nutrients to give fair high yields (e.g. Adegbidi et al. 2001). Nutrient removal at harvest negatively effects both the nutrient cycling and productivity of these cropping systems (Adegbidi et al. 2001). Inorganic fertilizers, biosolids, green manure crops, municipal waste water and landfill leachates have been used to enhance biomass production by replenishing the soil nutrient reserves.

Objective

The objective of this study is to determine the biomass production of three willow clones under the effects of various rates of inorganic fertilizer and composted cattle manure and to determine a relationship between cutting diameter and subsequent tree heights.

Material and Methods

Soil was collected from the top 30 cm of a pre-existing 4 year old willow plantation at the Kernen Crop Research Farm in Alberta, just between the Saskatchewan border. Each bulk of the Pine Association and the texture ranged from sand to loam, sand. The soil was air dried and sieved through a 2mm sieve. Willow cuttings were made from three clones of dormant one year old trees from a Saskatoon plantation (Table 1). Material was cut into 15cm cuttings and were planted in pots and cells (Stecklings) 15cm in depth. At the time of planting the cutting diameter were measured. Fertilization treatments were applied. These consisted of granular ammonium nitrate at 50, 100, and 200 kg N/ha. Composted cattle manure at 100, 300 kg N/ha as well as a control. The granular fertilizer was hand broadcast and the manure was incorporated into the top 5cm. Water was added to each pot at planting and every other subsequent day to maintain a soil water content of 70% field capacity (~0.32m³ m⁻³). Plastic bread wrap was placed across the soil surface to minimize evaporation. The pots were staged for the growth chamber in a completely randomized design. The trees will be grown for 90 days.

Measurements of tree heights and the number of shoots per tree will be recorded throughout the experiment.

Table 1. Willow clone information.

Clone	Parentage	Gender	Origin
Tully Champion	[illegible]	F	SUNY-ESF
Marcy	S. sachalinensis x S. miyabeana	F	SUNY-ESF
India	S. dasyclados	F	ESF

Results

Sprouting of cuttings was first observed on day 7 for all but four pots and the tree heights continued to increase (Figure 1).

Variation in tree heights has been observed for the three clones in the order of Tully Champion>Marcy>India (Figure 2). Marcy has been affected by disease which may have restricted the trees from reaching maximal heights at the point in the experiment (Figure 4). Symptoms included shriveling of leaves and blackening along veins and complete senescence of leaves.

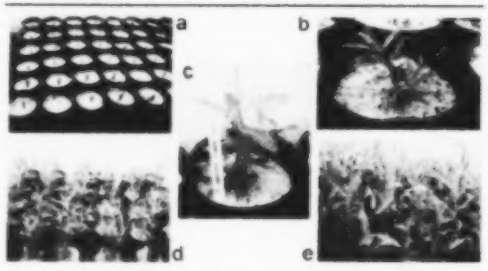

Figure 1. Cuttings at the growth chamber experiment (a) day 0, (b) day 3, (c) day 4, (d) day 40 and (e) day 45.

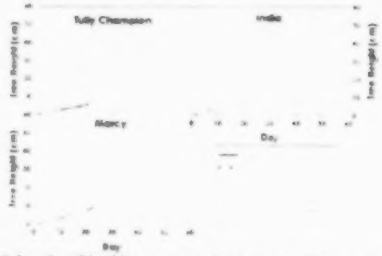

Figure 2. Tree heights of three willow clones grown under various fertilizer treatments: ammonium nitrate and composted cattle manure.

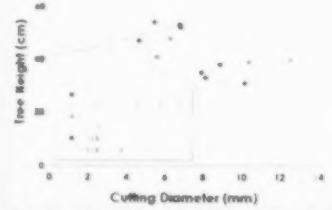

Figure 3. Relationships between cutting diameter and tree heights for 3 clones under the control treatment.

Figure 4. Selected Marcy trees on day 47 of the experiment.

Some distinct differences can be seen between the fertilization treatments for the three clones. The compost cattle manure application appears to be resulting in a slight negative response for three clones when compared to other treatments.

Surprisingly, the control treatment resulting in a large response for the India clone. Ammonium nitrate fertilizer amounts all three clones. The results still need to be analyzed for the significance of application.

Of the control treatments for the three clones, the tree height was plotted against the cutting diameters (Figure 3). Tully Champion shows a positive relationship between cutting diameter and tree height as tree height while both India and Marcy show a negative relationship. There is a significant effect of cutting diameter on tree height for Tully Champion ($p<0.05$) but not for India or Marcy. It appears that the point in the experiment that the effect of cutting diameter on height is most significant.

Conclusions

The results thus far are showing that Tully Champion has the greatest ability to reach taller heights. The clones are showing to respond well to the application of composted cattle manure and not to the granular ammonium nitrate. The data also suggests that tree height is not a function of cutting diameter but the diameter of cuttings.

Future Work

The future work of the experiment is to continue until the shoots are 90 and analyze the data collected from the entire study.

Sources

Adegbidi, H.G., R.D. Briggs, T.A. Volk, E.H. White, and I.P. Abrahamson. 2003. Effect of organic amendments and slow-release nitrogen fertilizer on willow biomass production and soil chemical characteristics. Biomass and Bioenergy. 25:389-398.

Adegbidi, H.G., T.A. Volk, E.H. White, I.P. Abrahamson, R.D. Briggs, and D.H. Bickelhaupt. 2001. Biomass and nutrient removal by willow clones in experimental bioenergy plantations on New York State biomass and Bioenergy 20:399-411.

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Nitrogen Uptake by Willow Bioenergy Cropping Systems in Saskatchewan, Canada

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Introduction

Objectives

Methodology

Table 1. Willow clone information.

Clone	Parentage	Gender	Origin
Tully	S. viminalis x S. miyabeana	F	Smith-ESF
Matrix	S. sachalinensis x S. miyabeana	F	Smith-ESF
Preble	S. dasyclados	F	CFS
Sacatoga	S. purpurea x S. miyabeana	F	Smith-ESF

Figure 1. Field pictures: a) application of the 15N, 13C solution, b) tree after fertilizer and label application.

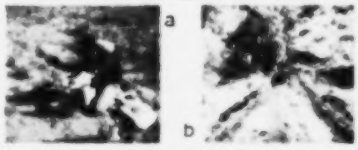

Figure 2.

Results

Biomass distribution

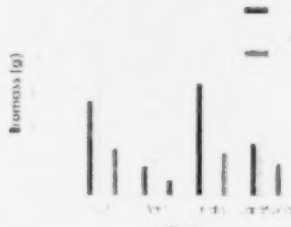

Figure 3.

Nitrogen Fertilizer Recovery

Figure 4. Nitrogen fertilizer recovery by the four clones for each plant part. Bars with different letters are significantly different within clones, those without are not.

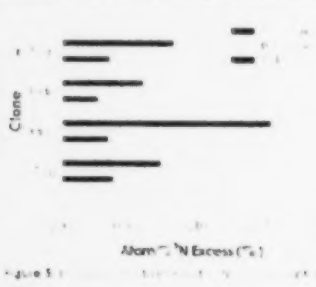

Figure 5.

Labelled fertilizer distribution in the soil

Conclusions

Sources

• Adegbidi H.G., R.D. Briggs, T.A. Volk, E.H. White and L.P. Abrahamson. 2003. Effect of organic amendment and site-reference nitrogen fertilizer on willow biomass production and soil chemical characteristics. Biomass and Bioenergy. 25:389-398.
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Acknowledgements

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